

Fishery Data Series No. 16-42

Status of Sheefish in Highpower Creek and Upper Kuskokwim River, 2012-2015

**Final Report for Study 12-312
USFWS Office of Subsistence Management
Fisheries Division**

**by
Lisa Stuby**

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Alaska Department of Fish and Game

Divisions of Sport Fish and Commercial Fisheries



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Weights and measures (metric)		General		Mathematics, statistics	
centimeter	cm	Alaska Administrative Code	AAC	all standard mathematical signs, symbols and abbreviations	
deciliter	dL	all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.	alternate hypothesis	H _A
gram	g	all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.	base of natural logarithm	<i>e</i>
hectare	ha			catch per unit effort	CPUE
kilogram	kg			coefficient of variation	CV
kilometer	km	at	@	common test statistics	(F, t, χ^2 , etc.)
liter	L			confidence interval	CI
meter	m			compass directions:	correlation coefficient
milliliter	mL	east	E	(multiple)	R
millimeter	mm	north	N	correlation coefficient (simple)	r
Weights and measures (English)		south	S	covariance	cov
cubic feet per second	ft ³ /s	west	W	degree (angular)	°
foot	ft	copyright	©	degrees of freedom	df
gallon	gal	corporate suffixes:		expected value	<i>E</i>
inch	in	Company	Co.	greater than	>
mile	mi	Corporation	Corp.	greater than or equal to	≥
nautical mile	nmi	Incorporated	Inc.	harvest per unit effort	HPUE
ounce	oz	Limited	Ltd.	less than	<
pound	lb	District of Columbia	D.C.	less than or equal to	≤
quart	qt	et alii (and others)	et al.	logarithm (natural)	ln
yard	yd	et cetera (and so forth)	etc.	logarithm (base 10)	log
Time and temperature		exempli gratia		logarithm (specify base)	log ₂ , etc.
day	d	(for example)	e.g.	minute (angular)	'
degrees Celsius	°C	Federal Information Code	FIC	not significant	NS
degrees Fahrenheit	°F	id est (that is)	i.e.	null hypothesis	H ₀
degrees kelvin	K	latitude or longitude	lat or long	percent	%
hour	h	monetary symbols		probability	P
minute	min	(U.S.)	\$, ¢	probability of a type I error	
second	s	months (tables and figures): first three letters	Jan,...,Dec	(rejection of the null hypothesis when true)	α
Physics and chemistry		registered trademark	®	probability of a type II error	
all atomic symbols		trademark	™	(acceptance of the null hypothesis when false)	β
alternating current	AC	United States		second (angular)	"
ampere	A	(adjective)	U.S.	standard deviation	SD
calorie	cal	United States of America (noun)	USA	standard error	SE
direct current	DC	U.S.C.	United States Code	variance	
hertz	Hz			population sample	Var var
horsepower	hp				
hydrogen ion activity (negative log of)	pH				
parts per million	ppm	U.S. state	use two-letter abbreviations		
parts per thousand	ppt, ‰		(e.g., AK, WA)		
volts	V				
watts	W				

FISHERY DATA REPORT NO. 16-42

**STATUS OF SHEEFISH IN HIGHPOWER CREEK AND UPPER
KUSKOKWIM RIVER, 2012-2015**

by

Lisa Stuby

Alaska Department of Fish and Game, Division of Sport Fish, Fairbanks

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1599

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*Lisa Stuby,
Alaska Department of Fish and Game, Division of Sport Fish,
1300 College Road, Fairbanks, AK 99701-1599 USA*

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ABSTRACT

This study was initiated to determine the status of the sheefish *Stenodus leucichthys* spawning population in Highpower Creek and Swift Fork, which are both tributaries of the North Fork Kuskokwim River. Fifty-two radio transmitters were surgically implanted into sheefish during early to late summer of 2012–2014 at and near the mouths of the Katlitna and Takotna rivers, Blackwater Creek, and East Fork. The radiotagged sheefish were tracked using a series of up to 9 stationary tracking stations located from Aniak to Telida. Aerial tracking flights were conducted during the time of spawning in late September and early October. During this time period, 18 sheefish traveled to the spawning area on the Tonzona River, 5 to the Middle Fork, 4 to the South Fork, and 14 to the Big River. Some of these fish were noted to repeat spawn and one South Fork spawner later spawned on the Big River. No radiotagged sheefish traveled to the mouth of Highpower Creek and Swift Fork during the fall spawning period, which implies this area is no longer a viable spawning area. Moreover, site visits to these areas (Highpower Creek, Swift Fork, and Tonzona River) to determine if sheefish are in spawning condition were completed and the spawning area on the Tonzona River was confirmed, whereas the Highpower Creek and Swift Fork area was not. Similar to previous years, upriver migration to sheefish spawning areas took approximately 1–2 months, with post-spawning outmigration taking 1 to 2 weeks during mid-to-late October. Aerial tracking flights documented pre-spawning milling behavior and later migration to their spawning locations. The majority of sheefish, spawners and non-spawners, migrated downstream to the Lower Kuskokwim River to overwinter. Results from a supplementary microchemistry analysis on sheefish otoliths from the Tonzona, Big River, and Middle Fork spawning areas corroborated what has been documented with this ongoing radiotelemetry study; sheefish from these spawning areas possess anadromous and non-anadromous life-histories. Habitat characteristics including dissolved oxygen, pH, and conductivity were similar among the designated spawning areas.

Key words: Kuskokwim River, Highpower Creek, South Fork, Big River, Middle Fork, East Fork, Tonzona River, Slow Fork, aerial tracking flight, sheefish, seasonal movements, spawning areas, *Stenodus leucichthys*, radio transmitter, stationary tracking stations

INTRODUCTION

The Kuskokwim River is the second-largest drainage in Alaska. From its headwaters in the Alaska Range, the Kuskokwim River drains approximately 130,000 km² along its 1,130 km course to the Bering Sea (Figure 1). This drainage supports 5 species of Pacific salmon as well as numerous resident species, including inconnu *Stenodus leucichthys*, commonly called sheefish in Alaska.

In Alaska, sheefish are a highly migratory, long-lived species that travel throughout most of the Kuskokwim River drainage and are important to both subsistence and sport fishers. Sheefish, like other whitefish, are known for their high phenotypic plasticity (Behnke 1972). A 5-year radiotelemetry study (Stuby 2012) was initiated in 2007 to extend our understanding of spawning characteristics of sheefish in the Kuskokwim River drainage. In particular, this study has identified 2 previously undocumented spawning areas in the Upper Kuskokwim River (Middle Fork Kuskokwim and Tonzona rivers); refined information on the most populous spawning area (Big River); and provided new information on migratory timing to spawning areas, spawning frequency, and spawning area fidelity. A fourth spawning area (South Fork Kuskokwim River) was identified in 2012 with this current study (Stuby 2013). However, none of the 119 sheefish that were radiotagged in 2007–2008 were detected at the mouth of Highpower Creek (Stuby 2012), which was described and documented as a spawning area by Alt (1972).

Currently and historically, the greatest use of sheefish in the Kuskokwim River drainage has been for subsistence with the majority of this harvest occurring in the Lower and Middle Kuskokwim River by fishers residing within the boundaries of the Yukon Delta National Wildlife Refuge. These sheefish provide a source of fresh fish prior to the salmon runs

(Chythlook 2009). Sheefish are primarily captured with gillnets in the occluded mainstem Kuskokwim River and with hook and line gear at the mouths of clearwater tributaries such as the Aniak River. Sheefish near the community of Crooked Creek are often captured through the ice during the winter (Evelyn Thomas, Crooked Creek resident, personal communication). Upper Kuskokwim River residents (Nikolai, Telida, McGrath, and Takotna) harvest sheefish throughout the summer, fall, and early winter (Stokes 1985). In Upper Kuskokwim River communities, sheefish are harvested using gillnets set underneath the ice in late fall and winter (Stokes 1985), and they are also caught incidentally and intentionally with gillnets and hook and line gear at fish camps throughout the summer (Holen et al. 2006). Residents of Nikolai often travel to the mouth of Big River in June to harvest sheefish. Prior to the 1990s, residents of Nikolai and Telida would travel up to the mouth of Highpower Creek during late August and early September to capture sheefish, in which many were fat and in pre-spawning condition (Williams et al. 2005; Steve Eluska, Telida resident, personal communication).

Sheefish are also an important targeted species by sport fishers in major tributaries within the Kuskokwim River drainage with the largest fishery occurring in the Holitna River (Chythlook 2012). Between 2005 and 2012, estimated sport harvest of sheefish within the Kuskokwim River drainage varied from 1,079 to 60, respectively (Chythlook 2014). Sport harvest estimates in the Holitna River drainage also varied from 349 in 2005 to 12 in 2010, which accounted for 8% to 100% of the total estimated sport harvest of sheefish within the entire Kuskokwim River drainage (Jennings 2011).

The mouth of Highpower Creek, and the Swift Fork Kuskokwim River (Swift Fork) into which it flows, was described and documented as a spawning area by Alt (1972). In 2010, a survey of this area noted that the habitat characteristics were unlike the Big River and Middle Fork spawning areas (Stuby 2012). An elder from Nikolai reported that he had observed sheefish spawning on the Swift Fork in late fall upriver from the mouth of Highpower Creek (Holen et al. 2006). Through conversations with residents of Telida and Nikolai, it was determined that sheefish were seen in abundance and harvested at the mouth of Highpower Creek throughout September during the 1980s and earlier but have not been seen in the past 20 years.

Determining the status of the sheefish spawning population in Highpower Creek and completing genetic baseline sampling of sheefish spawning populations were identified as priority research needs by the 2012 Fisheries Research Monitoring Program and the strategic plan for research of whitefish species in the Yukon and Kuskokwim River drainages (Brown et al. 2012). Management of sheefish populations for long-term sustainability requires a better understanding of their reproductive biology, life-history traits, and population size and composition. Identifying unique spawning stocks and their seasonal distributions and movements is essential for assessing their vulnerability and exploitation in the various subsistence and sport fisheries that occur throughout the Kuskokwim River drainage. Because sheefish appear to have very specific spawning habitat requirements and consequently spawn in very few areas (Stuby 2012, Alt 1987, Gerken 2009), documenting these areas is the necessary first step to ensure their habitats are protected. This project has continued the work started in 2007 to provide refined information on spawning locations, spawning frequency, fidelity to spawning areas, and migratory timing to and from spawning areas for Upper Kuskokwim River sheefish, especially Highpower Creek.

OBJECTIVES

The primary project objectives from 2012 to 2014 were to:

1. Determine the spawning status of sheefish in the Upper Kuskokwim River and in the vicinity of Highpower Creek by:
 - a. Documenting the locations of radiotagged sheefish during the spawning period;
 - b. Verifying spawning areas by conducting site visits and capturing fish to assess their spawning condition; and
 - c. Determining the migratory timing and seasonal distribution of radiotagged sheefish through aerial tracking surveys and ground-based stationary tracking stations;
2. Conduct site visits and capture sheefish to assess spawning condition in suspected spawning areas on the East Fork Kuskokwim River/Tonzona River;
3. Collect tissue samples from each sheefish captured at spawning areas for future genetic stock identification analysis; and
4. Describe habitat characteristics of the areas used for spawning.

METHODS

STUDY DESIGN

This project was designed as a 3-year study (2012–2014) but the transmitters typically last at least 3 years so radiotagged sheefish are still being tracked to this day. Due to the migratory nature of sheefish, this study has encompassed the majority of the Kuskokwim River drainage (Figure 1). The original project design was to implant 40 radio transmitters into sheefish captured on the North Fork Kuskokwim River (North Fork) and at the mouth of Highpower Creek during 2012 and to track their movements throughout the drainage from 2012 through the spring of 2016. Ten additional transmitters were purchased in 2013. Sheefish have been noted at the Big River and Middle Fork spawning areas 1–2 months prior to spawning (Stuby 2012). Therefore, half of the transmitters were to be deployed downriver of Telida and upriver of Medfra to compensate for uncertainty in migration dates or the inability to capture sheefish at the mouth of Highpower Creek because this spawning stock may be no longer viable (Figure 1). Based on Alt's previous work in the Kuskokwim River drainage and the feasibility work conducted by the Alaska Department of Fish and Game (ADF&G) in 1996 and 2004, it was assumed that most of the fish that were going to spawn in the upper portion of the drainage would travel through this area during the time of sampling. Internally implanted transmitters were used because results showed that this style of transmitter was less likely to adversely influence normal behavior than externally attached transmitters (Brown 2000). Radiotagged sheefish were tracked by fixed-wing aircraft to their spawning areas during late September and early October. In addition, the 9 stationary tracking stations located throughout the Kuskokwim River drainage (Figure 1) recorded timing of upstream and downstream migrations related to spawning, feeding, and overwintering. Radio transmitters that were not deployed in 2012 and 2013 or were returned by fishermen were deployed in 2014.

CAPTURE AND TAGGING

During 2012, attempts were made to deploy 40 radio transmitters into sheefish that were captured and tagged on the North Fork approximately 2–3 miles above the confluence of the East Fork Kuskokwim River (East Fork) during 18–28 August and at Highpower Creek during 11–18 September (Figures 1–2). A crew of 3–4 people captured sheefish with 5⅜ in cable lay gillnets using drift and set netting techniques as well as hook and line gear. All sheefish were retrieved with a soft landing net. Trips were taken up Highpower Creek to look for sheefish that may have travelled further up this drainage; a trip was also made up the Swift Fork approximately 7 km from the mouth of Highpower Creek. Hook and line gear was primarily employed at the uppermost extents of sampling in these 2 drainages due to shallow and swift water conditions precluding use of set nets.

During 2013, attempts were made to deploy any remaining transmitters from 2012 plus the 10 transmitters purchased in 2013. In late June and early July, hook and line techniques were used at the mouths of the Takotna and Katlitna rivers (Figure 1). During August, drift gillnet techniques were used on the North Fork above the confluence with the East Fork. Also, during 23–27 September, set net and hook and line gear were used at and near the mouth of Highpower Creek.

During 2014, all remaining sheefish transmitters were deployed from mid-to-late June and early July at the mouths of Blackwater Creek and the Katlitna River using hook and line techniques (Figure 1). Fifteen of these transmitters were left over from the previous year because of the inability to capture sheefish at the mouth of Highpower Creek, and 2 transmitters were returned to the project biologist from subsistence fishers and redeployed.

All sheefish greater than 650 mm FL and deemed to be in healthy condition were radiotagged because Stuby (2012) showed that fish of this size in the Kuskokwim River drainage were likely to be mature. Fish that showed signs of stress and/or injury due to capture were released without receiving a radio transmitter. Radio transmitters were surgically implanted following the methods detailed by Brown et al. (2002). For each sheefish that was captured and implanted with a radio transmitter, data collected included: measurement of fish length from snout to fork of tail (fork length; FL) to the nearest 5 mm, gender, spawning readiness, GPS location, transmitter frequency and code, date of capture, and any notable condition information.

A small pelvic fin clip was collected from each radiotagged sheefish. Each tissue sample was cleaned and immediately placed in an individually labeled vial filled with desiccant and later shipped to the United States Fish and Wildlife Service (USFWS) Conservation Genetics Laboratory in Anchorage. The samples were added to others collected in the Kuskokwim River drainage and will be used to establish a genetic baseline for sheefish from the Yukon and Kuskokwim rivers (OSM Project 12-700), which will allow for identification of different stocks that will aid in future conservation and management efforts.

RADIOTRACKING EQUIPMENT AND TRACKING PROCEDURES

Sheefish were surgically implanted with 3V micro-coded radio transmitters that are 1.5 cm in diameter and 5 cm long, with a wire whip antenna about 42 cm long (Lotek¹ model MCFT-3A), and were programmed with a 3 s burst rate. Each radio transmitter was distinguishable by a unique frequency of 149.200 MHz with 50 encoded pulse patterns for a total of 50 uniquely

¹ Product names used in this report are included for completeness but do not constitute endorsement.

identifiable transmitters. The transmitters were programmed to transmit continuously and were guaranteed by the manufacturer (Lotek) to operate for a minimum of 3 years.

Radiotagged sheefish were tracked using an array of stationary tracking stations located from Aniak to Medfra. The main purpose of the stationary tracking stations was to record the upstream and downstream timing of radiotagged sheefish to the Upper Kuskokwim River spawning areas. Information recorded by the stations also allowed the project biologist to allocate aerial radiotracking effort.

The 9 stationary tracking stations used in 2012–2015 were located 1) on the Kuskokwim River above Aniak; 2) on the Kuskokwim River below the George River; 3) near the mouth of the Holitna River; 4) on the Kuskokwim River below Stony River; 5) on the Kuskokwim River a few bends upriver from McGrath; 6) on the Middle Fork near the confluence with the Big River; 7) on the Kuskokwim River at Medfra; 8) on the South Fork below Nikolai; and 9) at Telida (Figure 1). The stationary tracking stations near Nikolai and at Telida had Lotek SRX_400 receivers and the other 7 had SRX_600 receivers. Each tracking station was powered by four 12 V deep cycle batteries that were charged with two 85W or higher solar panels set up in parallel. A water-resistant steel box covered with a fitted tarp housed the components. Two 4-element Yagi antennas were mounted on a mast elevated 2–10 m above the ground depending on the elevation of the site above the river. One antenna was aimed upstream and the other downstream. The receivers were programmed to scan through the frequencies at 8 s intervals and receive from both antennas simultaneously. When a signal of sufficient strength was encountered, the receiver paused for 6 s on each antenna, and then transmitter frequency, transmitter code, signal strength, date, time, and antenna number were recorded on the receiver. The relatively short cycle period minimized the chance that a radiotagged fish would migrate past the tracking station without being detected.

Most of the stationary tracking stations with SRX 600s had satellite modems attached to the receivers. The modems allowed the project biologist to directly contact the receivers using a laptop computer with a standard telephone line. The stationary tracking stations with the exception of the one near Nikolai were maintained by ADF&G personnel. The stationary tracking station located just downriver of Nikolai was maintained by the Kuskokwim Native Association (KNA). All stations were programmed with the sheefish frequency and frequencies from other cooperative projects conducting research on resident species. During 2012–2015, the stations operated through early to mid-December before the batteries lost their charge. Given that spawning activities should be concluded by late October, the tracking stations would have detected most of the outmigrating sheefish before the batteries lost charge. The tracking stations usually charged back up by February or March with increasing light and warming spring ambient temperatures.

Two aerial tracking flights were conducted during late September and early October with the primary purpose of recording sheefish at known and potential spawning areas. Aerial tracking flights were conducted with one fixed-wing aircraft an0064 one person (in addition to the pilot), and utilized one Lotek SRX_600 receiver/scanner that was actively listened to by the project biologist and one SRX_600 that passively scanned and recorded any sheefish that the project biologist may have missed. All frequencies (including those from cooperative studies) were loaded into the receiver prior to each flight. Dwell time on each frequency was 4 s. Flight altitude ranged from 100 to 300 m above ground. Two H-antennas, one on each wing strut, were mounted such that the antennas received signals perpendicular to the direction of travel. During

each flight, sheefish were tracked from the Swift Fork above Highpower Creek, encompassing major tributaries, ending on the mainstem Kuskokwim River downriver from McGrath to just below the Katlitna River, which covered most of the upper drainage.

Assessing whether a sheefish was in a previously undocumented spawning area from aerial tracking flights and stationary tracking stations was subjective. The following criteria were considered when evaluating whether a sheefish was in a spawning area:

- 1) it was located during the likely time of spawning;
- 2) it was located in habitat consistent with spawning areas described by observations from past research;
- 3) it was located in close proximity to 1 or more other radiotagged sheefish;
- 4) it was located among a large aggregation of sheefish; and
- 5) there was a directed (probably upstream) migration immediately prior to being located in the fall aerial tracking flights.

SITE VISITS TO SHEEFISH SPAWNING AREAS

Site visits to the previously documented Highpower Creek/Swift Fork and undocumented Tonzona River spawning areas were made to verify that sheefish in these areas are in spawning condition. Following capture of a sheefish, attempts were made to express gametes with light finger pressure. Extrusion of gametes confirmed spawning readiness and most fish were released alive. A small proportion of captured sheefish were sacrificed and the gonads were visually inspected. Gonadosomatic indices (GSI) were calculated from each female sheefish sacrificed with gonad weight expressed as a percentage of body weight (egg weight/whole body weight) X 100 (Snyder 1983). Sagittal otoliths were removed for age and strontium distribution microchemistry analysis and fin tissue was removed from each fish for genetic analysis.

Spawning Habitat Characteristics

During site visits to sheefish spawning areas on the Tonzona River and Highpower Creek/Swift Fork, spawning habitat characteristics were measured using a HACH HQ Series portable meter, including water temperature, dissolved oxygen (DO), pH, and conductivity. Flow rate was measured with a Global Water Flow Probe 101 and water clarity was determined with a standard Secchi disk. Substrate descriptions were based on Compton (1962). Two Onset HOBO Water Temp Pro v2 temperature data loggers deployed in the Swift Fork near the mouth of Highpower Creek and on the Lower Tonzona River were lost due to ice movement after spring river breakup; however, one data logger that was deployed in 2011 on the Big River was successfully retrieved in 2012. The data loggers were programmed to record temperature every 30 minutes from deployment to retrieval throughout the spawning period.

DATA ANALYSIS

Standard sample summary statistics (Cochran 1977) were used to describe the upriver spawning distributions of sheefish. Recorded sheefish spawning locations from the aerial tracking surveys were consolidated, examined, and plotted using ArcGIS 10.2.2. Individual radiotagged sheefish were assigned a “fate” (Table 1). Fates of the all radiotagged sheefish were determined from a combination of information collected from stationary tracking stations and aerial tracking flights. Cumulative frequency distribution plots were used to describe migratory timing of sheefish

moving past stationary tracking stations during their upriver and downriver migrations to spawning and overwintering areas.

SUPPLEMENTAL MICROCHEMISTRY ANALYSIS OF SHEEFISH OTOLITHS FROM SPAWNERS

The migration chronology of sheefish through fresh, estuarine, and marine habitats of the Kuskokwim River drainage was described using microchemistry of 23 otoliths collected from spawning sheefish from the Middle Fork and Big River in September 2011. In September 2013, an additional 7 otolith pairs were collected from pre-spawning Tonzona River sheefish milling in the Slow Fork Kuskokwim River (Slow Fork).

One otolith from each pair was sectioned through the nucleus, encapsulating the distal to proximal edges. The otolith was first ground to the focus using a diamond-grinding wheel, mounted on a glass slide with Crystalbond Thermoplastic, and further ground to a thin section, encapsulating the focus in the transverse plane (Secor et al. 1991).

Strontium:Calcium (Sr:Ca) ratios reported in units of mmol:mol were determined using an Agilent 7500ce Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA-ICPMS) housed at the Advanced Instrumentation Laboratory at the University of Alaska Fairbanks. An argon laser ablated a transect for each otolith from the core perpendicular to the annuli and into the mounting medium. Laser speed was set at 5 $\mu\text{m/s}$ with a 25- μm spot diameter on a single pass transect set to 80% power (Neher et al. 2013). The excited ions in the plasma torch were subsequently introduced to a mass spectrometer detector for both elemental and isotopic analysis. The elemental count(s) output of the LA-ICPMS were then converted to concentrations with sampling distance using the elemental weights for each constituent and with the laser settings (Neher et al. 2013). After analysis with the LA-ICPMS, the Middle Fork and Big River otoliths were ground thin and ages were acquired with a compound microscope (Stuby 2014).

Brown et al. (2007) reported that coregonid fish like sheefish were considered anadromous if the maximum Sr concentration was greater than 1,700 mg/kg, and otherwise the fish would be considered to be non-anadromous. According to Randy Brown (USFWS fishery biologist in Fairbanks, AK, personal communication) a Sr:Ca (mmol:mol) value of 2.0 is equivalent to a Sr ppm value of 1,700. In addition, the relationship between Sr ppm and Sr:Ca (mmol:mol) is linear and highly correlated. Because Ca is essentially a constant in the Sr:Ca ratio, nearly all variability of the ratio will be a result of Sr variability.

RESULTS

A total of 52 sheefish were captured and radiotagged throughout the Upper Kuskokwim River from 2012–2014. Twenty-seven transmitters were deployed on the North Fork in 2012–2013, 8 more were deployed at the mouths of the Takotna and Katlitna rivers in 2013, and the remaining 17 were deployed in 2014 at the mouths of Blackwater Creek and the Katlitna River.

The majority of the 52 radiotagged sheefish were not detected alive and moving in 2015 or were documented mortalities (Table 2). Of the 25 sheefish that were captured and implanted with radio transmitters during August 2012, only 4 were detected alive and moving in 2015 (Table 2). Of the 10 fish radiotagged in 2013, half were not detected upriver in 2015 (Table 2). Likewise, less than half of the 17 sheefish that were radiotagged in 2014 were not detected upriver in 2015. Overall only 15 radiotagged sheefish were detected upriver above Aniak in 2015. Stuby (2012)

showed that of the 119 radio transmitters that were deployed, the majority outlasted their 3-year warranted life. Therefore, transmitter failure is not suspected to be the primary reason the majority of radiotagged sheefish from the current study were not detected 1 to 3 years after tagging.

Each year a proportion of the radiotagged sheefish travelled to upriver spawning locations (Figure 3). During 2012–2015, the majority of spawning sheefish (21 out of 47) travelled to the Tonzona River and were located during the time of spawning between the mouth and approximately 5 km below the confluence with Dennis Creek (Table 3, Figure 4). The proximity of this spawning location to the tagging site near the mouth of the East Fork probably accounted for the higher proportion spawning in this drainage (27 sheefish tagged in 2012 and 2013). The majority of sheefish (22 out of 47) from the other tagging locations (Blackwater Creek, Takotna River, and Katlitna River) travelled to the Big River and Middle Fork spawning areas to spawn (Table 3, Figure 5). Most of the sheefish that traveled to the Big River and Middle Fork during 2014 were located further up the spawning drainages compared to previous years (Figure 5). Inclement weather precluded flying over these drainages in 2015.

During 2012, 4 sheefish travelled to an approximately 15 km area on the South Fork above Nikolai and just above the confluence with the Little Tonzona River (Table 3, Figure 6). These fish met the criteria established for evaluating whether or not this area represents an additional undocumented spawning location. Previous radiotelemetry work on sheefish never detected spawning sheefish in this area (Stuby 2012) and no radiotagged sheefish were noted to travel to the South Fork during 2013–2015. However, one spawner that had not been detected since 2013 was recorded swimming upstream past the Aniak tracking station in early April 2016 and based on spawning fidelity could possibly be returning to the South Fork this year to spawn.

Radiotagged sheefish showed pre-spawning milling behavior. During 2008–2012, radiotagged sheefish were detected at or near the confluence of the Tonzona River with the East and Slow forks (Figure 4) and were not detected near their spawning locations further up the drainage until 2013–2015. However, the first aerial tracking flight on 23 September 2014 was early enough to show this pre-spawning milling behavior at the mouth of the Slow Fork and later upriver movement with the 2 October 2014 flight because the fish had travelled to their spawning locations. Similar pre-spawning and spawning movement was also noted for the Big River and Middle Fork (Figures 7 and 8).

Similar to previous studies (Stuby 2012), some radiotagged sheefish were noted to repeat spawn. One Tonzona River male sheefish spawned during 2012 and again in 2014 and 2015; three additional Tonzona River sheefish were noted to repeat spawn during consecutive or alternating years (Table 4). Repeat spawning was also noted for some Middle Fork and Big River sheefish. One female, tagged in 2007 and located in the Big River spawning area, was detected at the Big River again in 2009–2012, thus having spawned 4 years in a row and 5 of 6 years total. Another sheefish captured and tagged in 2008 of unknown gender returned to the Big River during 5 consecutive years (2008–2012) to spawn (Stuby 2013). The 4 spawning sheefish that travelled to the Big River and Middle Fork in 2015 were repeat spawners; however, we were unable to decipher their exact location from an aerial flight due to inclement weather and, although rare, straying behavior has been noted between these 2 spawning locations (Stuby 2012). In addition, a fish that travelled to the South Fork during the time of spawning in 2012 later travelled up the Big River in 2014.

No radiotagged sheefish were observed to travel to Highpower Creek and the Swift Fork during all years of this study, which was consistent with all the previous radiotelemetry work in the Kuskokwim River drainage (Stuby 2010 and 2012). With the aerial tracking flights, stationary tracking station located at Telida, and intensive site sampling in a relatively small area during mid-to-late September 2010, 2012, and 2013, it can be concluded this area is no longer a viable sheefish spawning location.

The upstream and downstream migrations of sheefish to their spawning locations on the Big River and Middle Fork for 2014 and 2015 showed similar trends to 2008–2011 (Figure 9). Distances to the Blackwater Creek tracking station are similar for these 2 spawning locations (74 km to the Middle Fork and 48 km to the Big River). The radiotagged fish bound for these spawning areas generally arrived over a period of approximately 1–2 months. The earliest average arrival date was 12 August 2014 and the latest was 26 August 2010. The earliest date a sheefish was noted to arrive (3 July 2011) was on the Middle Fork and the latest (19 September 2008) was on the Big River. Post-spawning outmigration was more compressed and occurred over a 1–2 week period in October (Figure 9). The earliest average date of departure was 9 October 2009 and the latest was 15 October 2008. The earliest date a sheefish was noted to pass by the stationary tracking station at Blackwater Creek was 23 September 2008 from the Big River; this date may be an outlier because no other fish were noted to leave this early. The latest was 24 October 2008, also from the Big River (Figure 9).

Similar to the Big River and Middle Fork spawners, the radiotagged sheefish on the Tonzona River arrived over a relatively extended time period and left over a short time period (Figure 10). The earliest fish arrived on 13 June 2015 and the latest on 11 September 2012. The average date of upriver passage for the 15 fish detected travelling upriver past the stationary tracking station at Medfra for 2008–2015 was 10 August. The outmigration for 2012 was later than previous years. The earliest post-spawning sheefish travelled past the stationary tracking station on 4 October 2008, and the latest post-spawning sheefish was recorded on 22 October 2014. The average date of downriver passage for 22 fish detected past the stationary tracking station at Medfra for 2008–2015 was 16 October.

Run timing of the Tonzona River spawning sheefish past the McGrath tracking station for pre- and post-spawning sheefish followed similar trends to Big River and Middle Fork spawning sheefish (Figure 11). The average pre-spawning Tonzona River sheefish arrived approximately 9.1 days later than Middle Fork and Big River spawners in 2014 and 14.1 days earlier in 2015. For the same years, the average post-spawning date sheefish passed the tracking station was 1.6 days later in 2014 and approximately 0.9 days earlier in 2015. The similar post-spawning run timing belies the additional 125 km of travel distance to the Tonzona River spawning area. In 2012, the Tonzona River post-spawning outmigration showed a later run-timing pattern compared to previous years (Figure 11).

The Nicolai tracking station was the closest station to the probable spawning area on the South Fork, approximately 20 km downriver from the mouth of the Little Tonzona River. The earliest arrival date for the 4 spawning sheefish was 7 September and the latest was 11 September, with an average of 9 September (Figure 12). The earliest post-spawning outmigration date was 2 October and the latest was 25 October, with an average of 17 October (Figure 12).

Under-ice travel prior to spring river breakup and during the dead of winter was observed for a few radiotagged sheefish during 2012–2015. Two sheefish tagged in 2012 were seen to travel

past the Aniak tracking station under the ice during 16 January 2013 and 16 May 2013; the latter was 10 days prior to river breakup on 26 May 2013. Comparatively later run timing was seen for 2014, although breakup was earlier (1 May 2014). During 2015, the average upriver spring migration timing was earlier than previous years (Figure 13). In 2015, river breakup was on 4 May, which means 3 of the 14 sheefish travelled past this tracking station under the ice (Figure 13). The average date of passage was 30 May, 2 June, and 18 May for 2012, 2014, and 2015, respectively, which compared to previous studies (Figure 13; Stuby 2012).

During the fall downriver migration, also similar to previous work, non-spawning sheefish were recorded past the Aniak tracking station at least a week or more earlier than post-spawning sheefish (Figure 14; Stuby 2012). The earliest non-spawning sheefish travelled downriver past the Aniak tracking station on 24 August 2013 and the latest on 13 November 2012. In contrast, the earliest spawning sheefish passed this tracking station on 17 October 2014 and the latest on 19 November 2013. The earliest non-spawning sheefish passed the Medfra tracking station on 14 June 2014 and the latest passed on 3 August 2014.

Overwintering fates were based on radiotracking flights and stationary tracking station data. Similar to the previous study (Stuby 2012), the majority of sheefish overwintered in the Lower Kuskokwim River (Table 2). Between 2012 and 2015, 5 fish spent one or more winters between the mouth of the East Fork and McGrath (Stuby 2013–2015). One fish tagged in 2012 spent 2 winters in a row above Medfra, before being harvested in the subsistence fishery. During the winter of 2015 and 2016, one sheefish was noted to be spending the winter above McGrath and another between McGrath and Stony River.

GENDER AND LENGTH COMPOSITION

Twenty-five of the 52 sheefish that were radiotagged were positively identified as male (15) or female (10). Twenty-two of the 27 sheefish captured during August appeared to be pre-spawners compared to 4 out of 25 June/July captures. For pre-spawners, females were gravid with eggs, even in early summer. Gender could not be discerned for 27 sheefish. The smallest sheefish captured and radiotagged was 650 mm of unknown gender; the largest fish captured was a female that was 860 mm in length (Figure 15). The average length of the 52 radiotagged sheefish was 723 mm. Overall, the lengths of the females were larger than males and the majority fish with an unknown gender were closer to males (Figure 15).

SITE VISITS TO SHEEFISH SPAWNING AREAS AND SPAWNING HABITAT CHARACTERISTICS

Despite intensive efforts to capture and radiotag pre-spawning sheefish at the mouth of Highpower Creek and Swift Fork, no sheefish were captured (Figure 2). This was a relatively small system and numerous coho salmon and Arctic grayling were captured, often multiple times. Fishing conditions were excellent during the September 2012 and 2013 efforts. Lower Highpower Creek and the Swift Fork were flown during 2012–2015 and no radiotagged sheefish were detected. Moreover, tracking surveys were done under good conditions (clear and low water) and no sheefish were ever spotted from the air. In contrast, 63 sheefish were captured on the Slow Fork just downriver from the Tonzona River spawning area during 18–20 September 2013 and all were in pre-spawning condition. Eggs and milt were expressed with little pressure for all captured fish. Three female sheefish were sacrificed with an average GSI of 21.7%. Eggs were approximately 2.5 mm in diameter.

Environmental characteristics for the Tonzona River and Swift Fork were similar to the sheefish spawning areas on the Big River and Middle Fork (Figure 4, Appendix A1). Conductivity for the Tonzona River was approximately 75% higher (514 $\mu\text{S}/\text{cm}$) compared to the other spawning areas (Appendix A1). The DO at the mouth of the Slow Fork was comparatively lower (82.6% versus 97.5%) than the Tonzona River, as was conductivity (222 $\mu\text{S}/\text{cm}$ versus 514 $\mu\text{S}/\text{cm}$), which was similar to Highpower Creek and the nearby Swift Fork. Flow rate was not recorded, although the Slow Fork appeared to be much slower and less turbid (1.22 m Secchi depth) than the Tonzona River (0.28 m Secchi depth). The pH values were a little lower for the Slow Fork (7.58) than the Tonzona River (8.28 to 8.34). The water temperature of the Slow Fork and Tonzona River was similar at 3.7°C (Appendix A1).

One HOBO v2 temperature data logger that was deployed on the Big River in late September 2011 was retrieved during the aerial tracking flight on 1 October 2012. Water temperatures were recorded through most of the 2011 and 2012 spawning periods (Appendix A2). The average outmigration date past the station for 2011 was 12 October, although the last outmigrating sheefish was recorded on 19 October. Using 19 October as the final migration date, the average water temperature during this period was 3.21°C and ambient air temperature from the McGrath Station was 2.52°C (Appendix A2).

Slow Fork substrate was very similar to Highpower Creek and unlike that on the Tonzona River. The substrate at Slow Fork and Highpower Creek was composed of very fine, organic-rich material, unlike the substrate at the other Kuskokwim River sheefish spawning areas. The sedimentary structure on the Tonzona River and Swift Fork was similar to the Big River and Middle Fork sheefish spawning areas. Tonzona River and Swift Fork sediment was composed of varying sized gravel. The substrate on the shore was examined and is considered a good proxy to actual spawning habitat (Joe Buckwalter, ADF&G, Anchorage, personal communication). Using the Wentworth grain-size classification scheme (Compton 1962), substrate on the Tonzona River and the Swift Fork was characterized as very coarse to coarse pebble and cobble gravel to fine sand and silt. Sediments were moderately to poorly sorted with sub-rounded to rounded cobbles and pebbles. Sand and silt fills the interstitials between pebbles and cobbles.

SUPPLEMENTAL MICROCHEMISTRY ANALYSIS OF SHEEFISH OTOLITHS FROM SPAWNERS

Twenty of the 23 otoliths collected from sheefish captured on the Big River and Middle Fork during September 2011 and 4 of the 7 otoliths collected from Tonzona River spawning sheefish during September 2013 were successfully processed on the LA-ICPMS. Two of the 3 remaining otoliths from the Tonzona River were not processed and one had too much vaterite to determine the Sr:Ca ratio. One fish from each spawning location showed Sr:Ca mmol:mol values well above 2.0, which is a sign of marine influence and clear anadromy (Appendices B1 and B5). Another sheefish from each spawning location showed values above 2.0, but not to the same degree as the first fish, which was indicative of probable anadromy and/or brackish water influence (Appendices B2 and B5). The remaining sheefish showed primarily non-anadromous life history with probable encounters with slightly brackish water as in the Lower Kuskokwim River (Appendices B3–B5). Ages given for the Tonzona River spawning sheefish are from fin rays, which Stuby (2014) has shown to underage compared to otoliths, especially for larger and older fish. Ages were not determined for otoliths because the project biologist hopes to process the remaining 2 otoliths on the LA-ICPMS prior to grinding them all down thin enough to age.

DISCUSSION

The inability to detect sheefish above Aniak that were radiotagged during 2012–2014 could have been a result of migration behavior, unreported subsistence harvests, or transmitter failure. Stuby (2012) showed that approximately 25% of fish radiotagged in 2007 and 2008 spent one or more summers as well as winters in the Lower Kuskokwim River, primarily in the mainstem below Akiak, and in the Johnson and Kialik rivers. However, most of these fish were noted to travel upriver at some time to spawn during the 5-year study. One fish that was radiotagged in 2012 and had not been seen since 2013 was detected past the stationary tracking near Aniak 3 years later, indicating they can spend larger amounts of time living in the Lower Kuskokwim River. A higher percentage of the 119 sheefish that were captured and radiotagged during 2007 and 2008 were detected alive and moving several years later in 2011 (Stuby 2012) than was noticed with this current study. For this earlier project we flew the entire drainage during summer and fall. Most of the “alive and moving” fish were noted to travel above Aniak to spawning locations. It was assumed that many of the fish not detected in 2011 were not detected due to transmitter failure because the transmitters had surpassed their 3-year longevity guarantee (Stuby 2012). Nevertheless, a much higher percentage of fish were alive years later from the earlier tagging effort than was seen for the present project. Alt (1977) noted that a sheefish that received a spaghetti tag approximately 32 km up the Holitna River in 1968 was recovered below Nulato in the Yukon River in 1973. Therefore, some of the disappearance of transmitters for the current study could be due to the fish spending their summers downriver or even in a different drainage. During 2014 and 2015, efforts to conserve Chinook salmon in the Kuskokwim River drainage and subsequent voluntary restrictions on harvest increased the importance of resident subsistence species such as sheefish (John Chythlook, ADF&G Kuskokwim Area Management Sport Fish biologist, personal communication). The transmitters are guaranteed to operate for 3 years and Stuby (2012) showed that they often operate an additional year, so it is unlikely that too many would fail after 3 years operation. These fish will continue to be tracked through June/July 2016.

There was no relationship between where a fish was radiotagged and where it ended up spawning for fish captured in summer feeding locations during May–July. Wherever sheefish were captured and radiotagged within the Kuskokwim River drainage, from the mouth of the Johnson River to Blackwater Creek, they were noted to travel to 3 primary spawning areas: Big River, Middle Fork, and Tonzona River (Stuby 2012–2015).

Radiotagged sheefish have consistently displayed a prolonged upriver migration to their spawning areas and a condensed post-spawning outmigration. This pattern has been noted for sheefish spawning areas on the Mackenzie River in the Yukon Territory, Canada (Howland et al. 2000); Sulukna River in the Yukon River drainage (Gerken 2009); Selawik River (Hander 2014); and Kobuk River (Savereide 2016).

This study coupled with previous radiotelemetry work has shown that prior to spawning, sheefish exhibit milling behavior (Stuby 2012). Because sheefish arrive at spawning areas 1–2 months prior to spawning, in order to conserve resources, these fish typically find low-energy environments like back eddies and tributary confluences to mill (Stuby 2012). Alt (1987) noted that sheefish will congregate in deep water holding areas in the vicinity of spawning grounds, and as spawning time approaches, move upstream or downstream to the spawning areas. Stuby (2012) noted that sheefish began moving from their milling area at the mouth of Windy Fork to their spawning areas further up the Middle Fork on 22 September 2011, and nighttime spawning

activity was later noted on the Big River on 24 September 2011. For the Big River, sheefish were noted to reside in nearshore eddies a few miles below the spawning area before traveling further upriver to spawn. According to Steve Eluska, a long-time resident of Telida (personal communication), the confluence of Highpower Creek and the Swift Fork was a milling and resting place for sheefish that would travel further up the Swift Fork to spawn. The assumed relationship of sheefish milling in Lower Highpower Creek prior to spawning on the Swift Fork was seen in a similar system of the Slow Fork and Tonzona River. Habitat and water chemistry of the Slow Fork and Highpower Creek were similar, as were those of the Swift Fork and Tonzona River (Stuby 2014 and 2015). The 2 aerial tracking flights in 2014 captured the pre-spawning milling sheefish followed by movement to their spawning areas on the Big River, Middle Fork, and Tonzona River. However, spawning area locations were still approximate given sheefish typically spawn between 2000 and 0900 hours (Esse 2011) and aerial tracking flights cannot be conducted at night.

Each year outmigration dates showed some variation between years. One of the factors influencing outmigration timing may have been weather. Stuby (2012) noted that post-spawning outmigration of sheefish from the Big River and Middle Fork occurred earlier during October 2009 than other years, possibly due to relatively high ambient air and water temperatures and precipitation during the spawning event. An opposite effect occurred for spawning sheefish from the Tonzona River in 2012. The post-spawning downriver migration occurred comparatively later and may have also been a result of the record precipitation and higher than normal ambient air temperatures that occurred during mid-September (<http://pafg.arh.noaa.gov/>) prior to spawning. The earlier unseasonably warm weather and high water event may have kept the sheefish milling longer at the confluence with the Slow and East forks and may have even precluded fish traveling upriver to their spawning locations, because no movement was noted during the September and October aerial tracking flights. Such weather events prior to spawning may have caused a delay in spawning because the fish were waiting for flooding to subside and ambient air temperatures to drop. During the remaining years (2013–2015), weather was similar to the previous years (Stuby 2012) where sheefish arrived at the Tonzona River spawning area in early October.

Four sheefish radiotagged in 2012 in the North Fork travelled to what may represent an additional sheefish spawning area on the South Fork of the Kuskokwim River near the mouth of the Little Tonzona River. The 4 sheefish were in pre-spawning condition and gender was easily determined. The project biologist flew this drainage in 2012 on a suggestion from a resident of Nikolai who stated that sheefish do spawn in the South Fork. According to Stokes (1985) and Williams et al. (2005), residents of Nikolai typically fished for sheefish on the Lower Salmon and Big rivers during June and July and on the Upper Big River and Lower Highpower Creek from late August through late September. There was no mention in older and more current subsistence reports of sheefish being captured above Nikolai on the South Fork. Also, according to Alt (1972), residents in Nikolai told him sheefish do not spawn on the South Fork. Interestingly, one of these 4 spawners was detected travelling upriver in 2016 and will be followed throughout the summer to see if it revisits the probable South Fork spawning area in fall 2016. A site visit will be conducted in future years to determine sheefish spawning readiness and describe and compare this spawning area to others in the Upper Kuskokwim River drainage. Given that very few radiotagged sheefish have travelled to this location to spawn, it can be assumed that the spawning population must be comparatively small.

Sheefish have specialized spawning habitat needs that are similar amongst different tributary systems. According to Gerken (2009), sheefish spawning presence on the Sulukna River, a tributary of the Yukon River, was more likely if small cobble was the dominant substrate and gravel was the subdominant substrate. This was similar to what Stuby (2012) noted for the Big and Tonzona rivers and Middle and Swift forks where the shore substrate was composed of differentially sized gravel with varying degrees of sorting, sizes, and percentages of cobble, gravel, and sand. Observing similar substrates from flying low in a fixed-wing aircraft may help delineate the sheefish spawning area on the South Fork.

Sheefish appear to select spawning areas with fairly specific geologic features, which in turn are associated with specific water quality parameters (pH, temperature, and conductivity). The geology of the Big River and Middle Fork headwater regions are primarily composed of Paleozoic limestone that represent former alternating deep-marine and shallow-marine depositional environments in addition to mudstone and shale (Decker et al. 2004). The headwaters of the South and Swift forks and Tonzona River also contain metamorphic and sedimentary fossiliferous (limestone) rocks (Wahrhaftig 1965). Sulukna River geology is characterized by limestone, dolomite, and sandstone. This combination is common to other known sheefish spawning areas such as the Alatna, Selawik, and Kobuk rivers (Beikman 1980). The surficial and bedrock geology affects surface and ground water quality (Brabets et al. 2000). Gerken (2009) noticed that pH on the Sulukna River tended to be 8.0 or above, similar to the Big and Tonzona rivers and Middle and Swift forks of the Kuskokwim River. The pH in nearby Kuskokwim River tributaries during September is unknown. Gerken (2009) also noted that specific conductivity tended to be higher on the Sulukna River compared to other systems, specifically above 200 $\mu\text{S}/\text{C}$, which is consistent with what was observed on the Big and Tonzona rivers and Middle and Swift forks of the Kuskokwim River.

Other water quality parameters such as water temperature and flow may restrict establishment of sheefish spawning areas. Alt (1987) and Howland (2005) noted that preferred water temperatures for spawning tended to vary between 0°C and 6°C. Gerken (2009) observed that spawning within the Sulukna River began on 23 September when the mean water temperature was 4.5°C. In general, sheefish prefer habitat with fast-flowing, shallow water (Alt 1987, Howland 2005). In this study, early fall water temperatures as well as flow data on the Big and Tonzona rivers and Middle and Swift forks corresponded to studies in other systems.

Glacial influence is a characteristic of sheefish spawning areas in the Kuskokwim River drainage. The Big River primarily originates from glaciers in the Revelation Mountains, the Swift Fork from the Chedotlothna Glacier in Denali National Park, and the South Fork and Tonzona River from other glaciers in the Alaska Range. The Middle Fork is fed by 3 tributaries, one of which originates from a glacier. Groundwater and hyporheic flow are found in glacially-fed rivers (Malard, et al 2001). A McGrath resident told Alt (1972) that the water level in Big River remained high all winter compared to many glacial streams that had very low flow during winter. Two HOBO water temperature data loggers that were retrieved in September 2011 and October 2012 from the Big River recorded water temperatures near zero despite very low ambient temperatures (Stuby 2012, 2013). The contribution of hyporheic upwelling in sheefish spawning areas has been noted for non-glacial rivers such as the Sulukna and Selawik rivers (Gerken 2009). Groundwater flows act to maintain free-flowing water, moderate water temperature, limit ice development, and provide movement of nutrients and dissolved oxygen (Baxter and McPhail 1999). Conductivity has also been related to increases in hyporheic water

(Malcolm et al. 2009). This important phenomenon has not yet been documented for the sheefish spawning areas on the Kuskokwim River.

Although the lower 200 m of Highpower Creek was documented as the primary sheefish spawning area by Alt (1972), the habitat and water chemistry of the Swift Fork is more similar to the Big River and Middle Fork of the Kuskokwim River. According to Alt (1972) and personal communication in 2012, the substrate near the mouth of Highpower Creek was composed of differentially sized gravel when he visited this area in September 1971. During this time, Alt did not actually observe spawning behavior even though fish were in spawning condition. He also concluded the spawning habitat to be poor with turbid and slow-moving water with all spawning probably occurring on one gravel bar (Alt 1972). The differentially sized gravel Alt (1972) referred to in his report could be found in the Swift Fork. Not far up Highpower Creek the sediment was composed of fine, organic mud. Reshetnikov and Bogdanov (2011) observed that the highest proportion of sheefish egg mortality were for those that inadvertently settled in mud. Whether or not the habitat in this area has changed since Alt's visit in 1971 in a manner that has been detrimental to this spawning population is unknown. However, it can be assumed that any event(s) that would have adversely altered the spawning habitat in the lower 200 m of Highpower Creek would have also drastically changed the water chemistry. Both spawning substrate and water chemistry of the Swift Fork were similar to that observed at Big River and the Middle Fork (Stuby 2012, 2013). According to Steve Eluska, long-time resident of Telida (personal communication), the confluence of Highpower Creek and the Swift Fork was a milling and resting place for sheefish that would travel further up the Swift Fork to spawn. The project biologist similarly believes that sheefish may have used the slower-flowing Highpower Creek to rest prior to spawning on the Swift Fork.

Sheefish generally have shown fidelity to their spawning locations (Stuby 2012). However, in 2014 one of the sheefish that traveled to the spawning location on the South Fork in 2012 traveled to the Big River. Previously this straying behavior between spawning areas was noted for 2 fish on the Big River and Middle Fork (Stuby 2012). Because of similar characteristics of sheefish spawning habitat and proximity of the 2 areas, it is not too surprising that upriver migrating sheefish could get into a school heading to a different tributary to spawn. However, there is a distance of approximately 150 km between the Big River and South Fork. Brown and Burr (2012) documented 2 sheefish that strayed between the Alatna River and Yukon Flats spawning locations in the Yukon River drainage, which are unconnected and much further than 150 km. This further illustrates the plasticity of this species and capacity for straying.

The upper extent of sheefish spawning areas on the Big and Tonzona rivers and South Fork are where the rivers become less braided as one goes downriver with a primary channel where the sheefish congregate. Tanner (2008) noted in both the Tagagawik and Selawik rivers, sheefish spawned in areas with very high sinuosity and low slope, specifically in areas of transition from high to low elevations. According to Gerken (2009) the degree of channel confinement influenced the relationship between spawning substrate and the degree of width to depth ratio of the Sulukna River stream channel. The upper boundaries of the Big River and South Fork areas are where the elevation profiles show an abrupt increase (Ireland and Collazzi 1985a, 1985b). The elevation of the uppermost spawning area on the Big River is approximately 168 m (550 ft) above mean sea level and the South Fork is approximately 152 m (500 ft) above mean sea level. The uppermost radiotagged sheefish was detected close to the aforementioned upper boundary on the Big River in 2014. In contrast, the Middle Fork spawning area does not have such abrupt

increases or decreases with an elevation less than 152 m. In addition, GIS and fixed-wing aircraft observations illustrate how braiding decreases on the Swift Fork approximately 11 km upriver from the mouth of Highpower Creek and on the Tonzona River just below Dennis Creek. All of this evidence suggests sheefish spawning areas are also limited by the physical characteristics of the river itself.

A small proportion of radiotagged sheefish have been noted to overwinter in various middle and Upper Kuskokwim River locations above Bethel and Aniak, although the majority of radiotagged sheefish have been noted to spend the winter in the Lower Kuskokwim River and Kuskokwim Bay. One sheefish that was radiotagged in 2012 and overwintered above Medfra at or near the mouth of East Fork was captured in the subsistence fishery in June 2014 and found to be in good shape per a post-examination by the project biologist. Similarly, during the previous study, Stuby (2010) noted 3 sheefish spent the winter of 2008/2009 in the mainstem Kuskokwim River above McGrath, traveling downriver soon after breakup. These fish then spent the next few winters downriver. A few fish radiotagged in 2012 were doing similarly above Stony River and McGrath. Stuby (2010, 2012) also noted that a small proportion had overwintered in the Holitna River. One fish was noted to spend 3 winters on the Holitna River and the fourth downriver below Aniak, so this behavior may not be consistent. Stokes (1985) reported that sheefish have also been harvested on occasion in the Upper Kuskokwim River after freeze-up with nets set beneath the ice. Evelyn Thomas, resident of Crooked Creek (personal communication) told the project biologist that locals often catch sheefish under the ice during February. This phenomenon is not seen in all sheefish spawning systems such as the Kobuk River, where unless a mortality occurred, all post-spawning sheefish left the river to spend the winter in the brackish waters of Hotham Inlet (Savereide 2016). However, inriver overwintering behavior is not uncommon and has been documented in the Yukon and Tanana rivers (Brown and Burr 2012).

It was noted in Stuby (2012) that the majority of sheefish showed fidelity to their summer feeding areas between the Johnson and Tatlawiksuk rivers. This study has shown that the upriver tagging locations were also important summer feeding areas. Unlike the previous study (Stuby 2012), no aerial tracking flights were conducted during the summer to locate and examine summer feeding areas. However, the importance of these feeding areas were deciphered from tagging efforts, tracking station data, and aerial tracking flights. Kuskokwim River sheefish primarily spend their summers feeding at the mouths of major tributaries, which have encompassed almost the entire drainage, although some have spent summers in the Lower Kuskokwim River. Although this latest study was not designed to rigorously track sheefish during the summer, it has shown that the mouths of East Fork, Blackwater Creek, and Takotna and Katlitna rivers are also summer feeding destinations even though they are further upriver and therefore in greater proximity to spawning areas. Despite the proximity to the Tonzona River spawning area, 2 of the 27 sheefish captured and radiotagged near the mouth of the East Fork during 2012 and 2013 spawned on the Big River. Likewise, of the 3 sheefish radiotagged at Blackwater Creek, only one spawned on the Tonzona River. During 2013–2015, 5 sheefish that did not spawn travelled to the mouth of East Fork to feed. Only one fish that was radiotagged at the mouth of the Holitna River in 2008 was noted to travel to the Blackwater Creek and East Fork feeding locations during subsequent years (Stuby 2012). The majority of sheefish radiotagged during 2008 did not travel above McGrath until late summer and early fall to spawn (Stuby 2012). A notable exception is a sheefish tagged in August 2007 on the Takotna River at the mouth of Nixon Fork that returned to this location every year (2007–2012) to spend the

summer feeding (Stuby 2012). Most of these fish also overwintered in the Lower Kuskokwim River drainage and traveled upriver in spring soon after ice out.

The results of the microchemistry analysis on sheefish otoliths from the Tonzona and Big River and Middle Fork spawning areas corroborated what has been documented with the ongoing radiotelemetry study. Migration behavior of individual sheefish to their overwintering and feeding areas could be similar from year to year or variable. Overall, the otoliths showing primarily non-anadromous behavior with some brackish water influence is consistent with what has been noted in the radiotelemetry study. The otoliths from the Tonzona and Big River and Middle Fork spawning areas that clearly showed marine influence suggest that a proportion of sheefish do leave brackish water and spend time in the Kuskokwim Bay. Howland and Tonn (2001) noticed that some sheefish radiotagged on the Arctic Red River appeared to make regular seaward migrations throughout their life, whereas others made only estuarine migrations or occasional migrations to the sea followed by extended periods in a freshwater or estuarine environment. Therefore, it is not too surprising, as reported by Alt (1977), that one Kuskokwim River sheefish that was tagged on the Holitna River later traveled to the Yukon River. How often this phenomenon occurs is unknown, but based on the majority of otoliths having primarily freshwater and/or lightly brackish signatures, it is assumed to be sporadic. Although sheefish have been documented in the marine environment, Howland and Tonn (2001) suggest that they may lack blood antifreeze proteins that would allow them to withstand the subzero temperatures that occur in the Arctic Ocean during the winter. This problem has probably prevented the evolution, among Arctic salmonids, of extensive oceanic residency that is characteristic of many of their temperate relatives.

The variation seen in sheefish overwintering, feeding, and spawning migration behavior from year to year further illustrates the phenotypic plasticity of Kuskokwim River sheefish. The sheefish that showed clear anadromy were not part of a separate population from those who spent the majority of time in freshwater or slightly brackish water because sheefish spawn in relatively small stretches of the Big River (~20 km), Middle Fork (~8 km), Tonzona River (~13 km), and South Fork (~15 km) and are broadcast spawners (Stuby 2012–2015). To what degree all of the influences effect the different life-history strategies chosen by sheefish from these spawning areas through varying environmental conditions over several years (2007–2015) remains unknown, but undoubtedly the specific physical habitat characteristics and biological mechanisms required to spawn over multiple years while making numerous feeding and overwintering migrations are the limiting factors.

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TABLES AND FIGURES

Table 1.–List of possible fates of radiotagged sheefish in the Kuskokwim River.

Fate	Fate Description
Spawning Status	
Spawner	Sheefish located on a spawning area ^a during late September/early October. A sub-fate will be assigned to each of these fish indicating the specific area where the fish spawned.
Non-Spawner	Sheefish located during late September/early October but not on a spawning area.
Unknown Spawning Status	Sheefish not located during late September/early October.
Summer Feeding Status	
Summer Feeders	Sheefish was located during summer feeding period. A sub fate will be assigned to each of these fish indicating the specific area where the fish was located.
Unknown Summer Feeding Status	Sheefish was not located during summer feeding period.
Overwintering Status	
Overwintered in Lower Kuskokwim River	Sheefish traveled downriver past stationary tracking station located at Aniak during fall and traveled back upriver during early spring.
Overwintered in Upper Kuskokwim River	Sheefish detected in the fall aerial tracking flights upriver of the stationary tracking station at Sinka's Landing near the mouth of the Swift River in the fall and not detected by the stationary tracking stations to leave this area until after ice out in the spring.
Overwintered in Middle Kuskokwim River	Sheefish detected in the fall aerial tracking flights upriver of the Aniak stationary tracking station and downstream of the station at Sinka's Landing in the fall and not detected by either station to leave this area until after ice-out in the spring.
Overwintered in Holitna River	Sheefish documented in Holitna River during fall aerial tracking flights and not detected by the stationary tracking stations to have left in fall and/or winter.
Unknown Overwinter Location	Sheefish was not located during fall aerial survey or detected by a stationary tracking station during the fall or spring.
Mortality	
Tagging Mortality	Sheefish died in response to handling and transmitter implementation. Fish not seen to move within one year after tagging.
Harvest Mortality	Project biologist contacted by fisher that a radio-tagged sheefish has been harvested. Or, during multiple aerial tracking flights, project biologist documents radio transmitter signal clearly emanating from a village or fish camp.
Natural Mortality	Sheefish survived tagging and handling, but not seen to move in over a year and is not located near human settlements.

^a Spawning areas will be determined using the criteria listed in the Radiotracking Equipment and Tracking Procedures section.

Table 2.–Fates of sheefish in 2015 that were radiotagged during 2012–2014.

	Number fish tagged ^a	Harvest, tagging, or natural mortality	Not Detected above Aniak			Detected alive and moving	Spawning Behavior ^b		Overwintering Behavior		
							Spawned	Did not spawn	Lower Kuskokwim River	Near or above McGrath	Last detected at or near Stony River
			2013	2014	2015						
Tagged in 2012											
Males	12	2	6	7	8	2	1	1	2	0	0
Females	7	2	2	5	5	1 ^c	0	1	1	0	0
Unknown	6	3	2	2	2	1	0	1	1	0	0
Total	25	7	10	14	15	4	1	3	4	0	0
Tagged in 2013											
Males	1	0	-	0	0	1	1	0	0	1	0
Females	1	0	-	1	1	0	0	0	0	0	0
Unknown	8	0	-	5	4	4	4	0	3	0	1
Total	10	0	-	6	5	5	5	0	3	1	1
Tagged in 2014											
Males	2	0	-	-	0	2	1	1	2	0	0
Females	2	2	-	-	0	1	0	1	1	0	0
Unknown	13	0	-	-	8	4	1	3	4	0	0
Total	17	2	-	-	8	7	2	5	7	0	0
All Sheefish Tagged 2012-2014											
Males	15	2	6	7	8	5	3	2	4	1	0
Females	10	4	2	6	6	2	0	2	2	0	0
Unknown	27	2	2	7	14	9	5	4	8	0	1
Total	52	9	10	20	28	15	8	8	14	1	1

^a Two transmitters that were returned to ADF&G from subsistence fishermen were re-deployed in 2014.^b Of fish detected alive and moving in 2015.^c Sheefish that was captured, radiotagged, and noted to spawn on the South Fork in 2012, overwintered above Medfra, and was last noted to travel past Aniak in October 2013 and not detected until early April 2016, when it was noted travelling upriver past Aniak.

Table 3.—Numbers of radiotagged sheefish located at 4 spawning areas of the Kuskokwim River during 2012–2015.

Spawning Location	Year Tagged			Total
	2012	2013	2014	
2012				
Big River	1	-	-	1
Middle Fork	0	-	-	0
Tonzona River	9	-	-	9
South Fork	4	-	-	4
Total	14	-	-	14
2013				
Big River	0	1	-	1
Middle Fork	0	2	-	2
Tonzona River	2	1	-	3
South Fork	0	0	-	0
Total	2	4	-	6
2014				
Big River	2	0	7	9
Middle Fork	0	1	4	5
Tonzona River	3	1	1	5
South Fork	0	0	0	0
Total	5	2	12	19
2015				
Big River/Middle Fork ^a	0	2	2	4
Tonzona River	1	3	0	4
South Fork	0	0	0	0
Total	1	5	2	8

^a Due to inclement weather, unable to fly to Big River and Middle Fork spawning location and therefore unable to decipher exact spawning location.

Table 4.—Repeat spawning of sheefish radiotagged in the Upper Kuskokwim River during 2012–2015.

Year Tagged	Gender of Fish	Location and Year Spawned			
		2012	2013	2014	2015 ^a
2012	Male	Tonzona R.	-	Tonzona R.	Tonzona R.
2012	Unknown	-	Tonzona R.	Tonzona R.	-
2012	Male	South Fk	-	Big River	-
2013	Unknown	-	Middle Fk	Middle Fk	-
2013	Unknown	-	-	Tonzona R.	Tonzona R.
2014	Male	-	-	Middle Fk	Big R./Middle Fk
2013	Male	-	Tonzona R.	-	Tonzona R.
2013	Unknown	-	Middle Fk	-	Big R./Middle Fk
2013	Unknown	-	Big R.	-	Big R./Middle Fk

^a Due to inclement weather, unable to fly to Big River and Middle Fork spawning location and therefore unable to decipher exact spawning location.

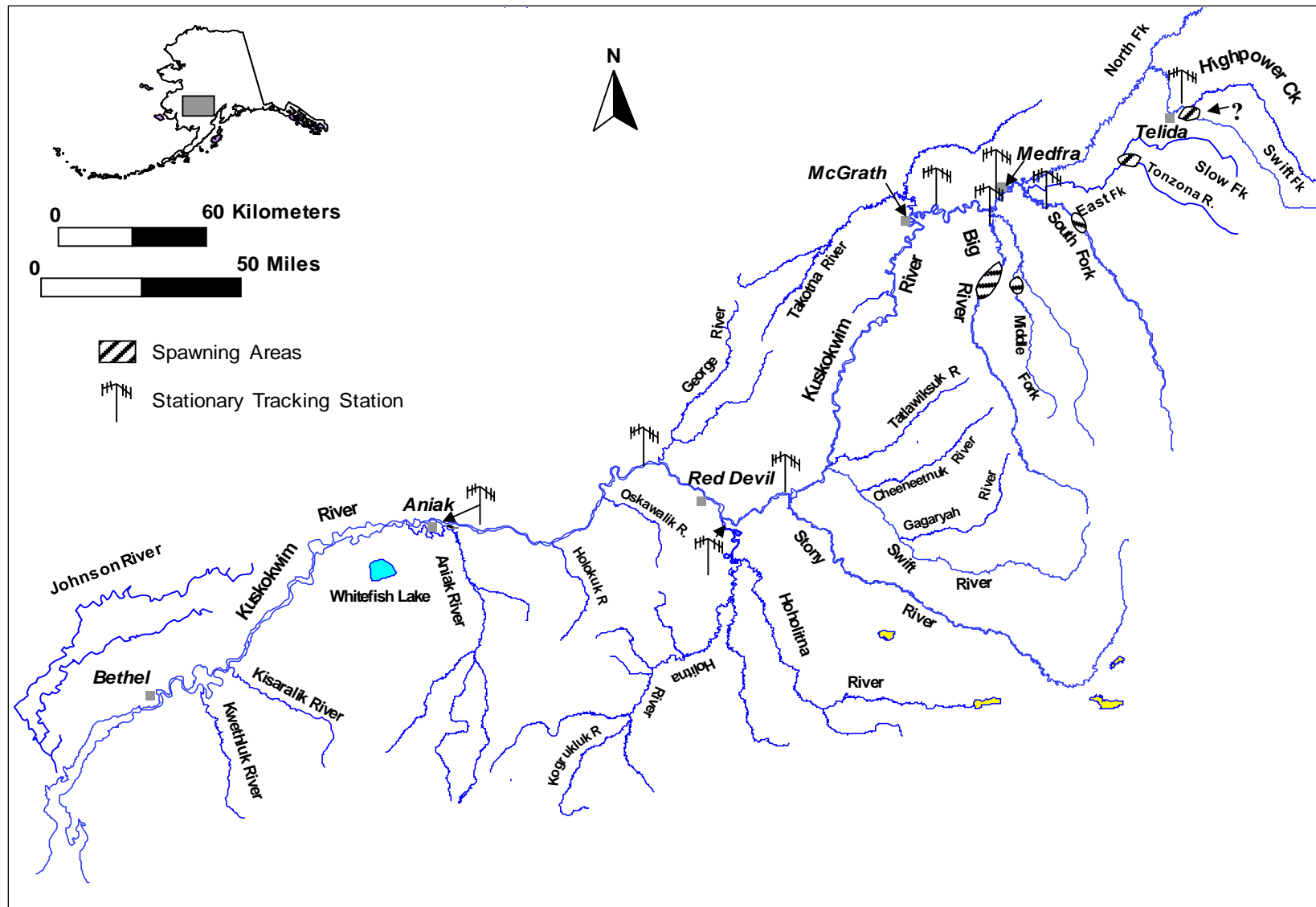


Figure 1.—Map of the Kuskokwim River showing stationary tracking station locations used in 2012–2015 and approximate spawning locations for sheefish noted in this study and from Stuby (2012).

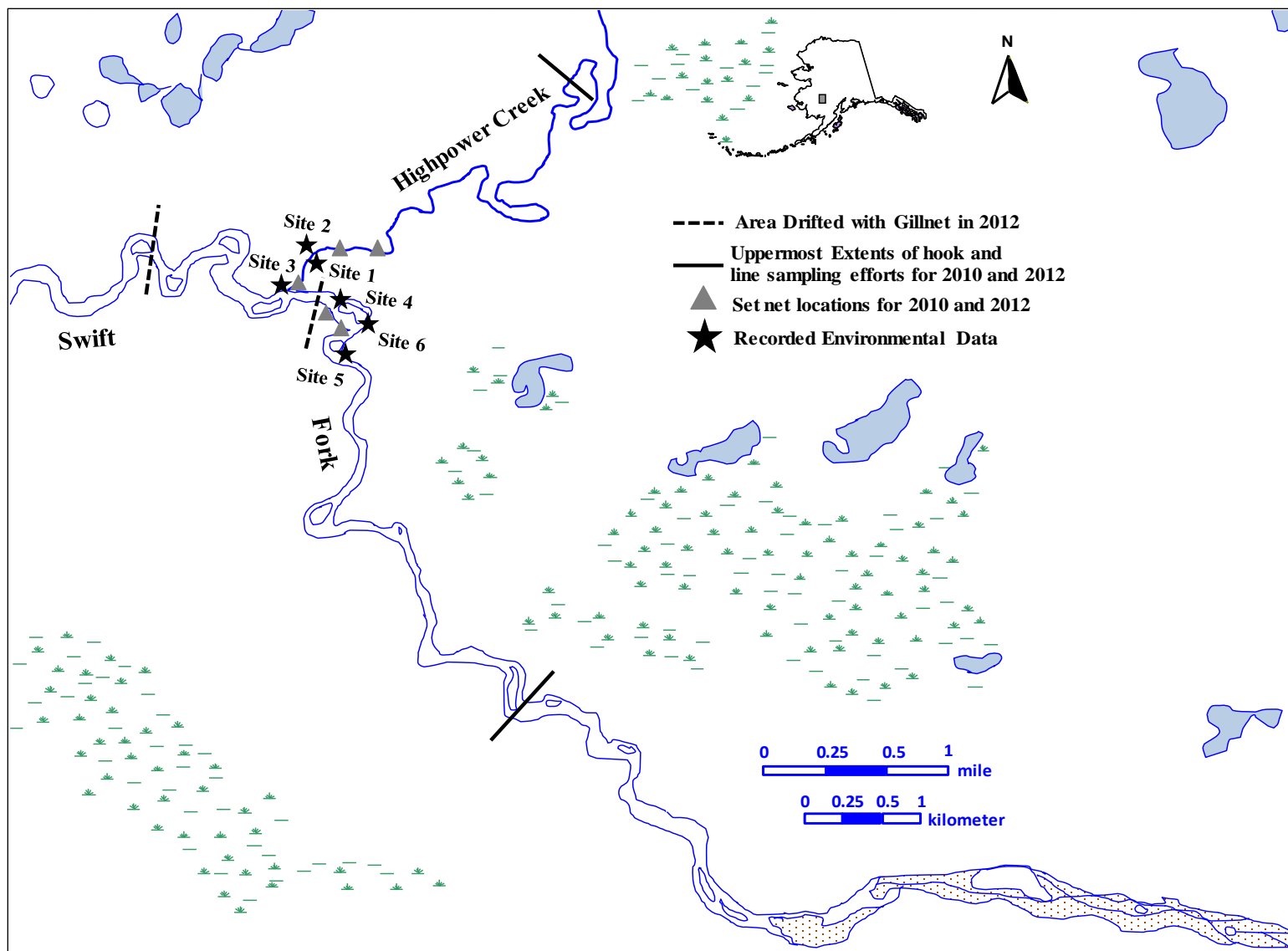


Figure 2.—Set net sites, area drifted with gillnet, and extent of hook and line efforts for 2010 and 2012 on Highpower Creek and the Swift Fork Kuskokwim River. Environmental data recorded in 2012 are listed in Appendix B1 for each site.

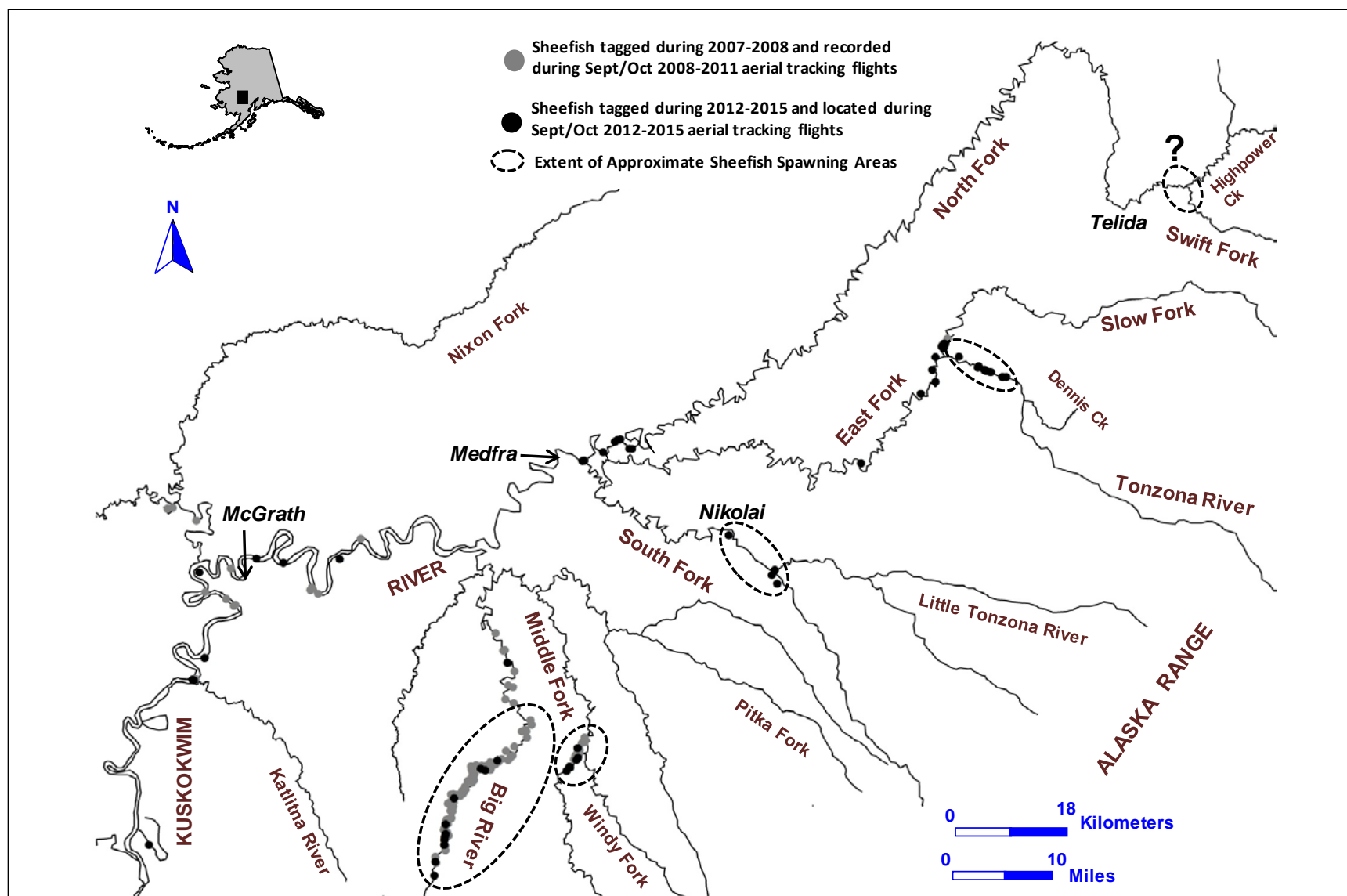


Figure 3.—Locations of radiotagged sheefish in documented spawning areas in the Upper Kuskokwim River drainage during September and October 2012–2015.

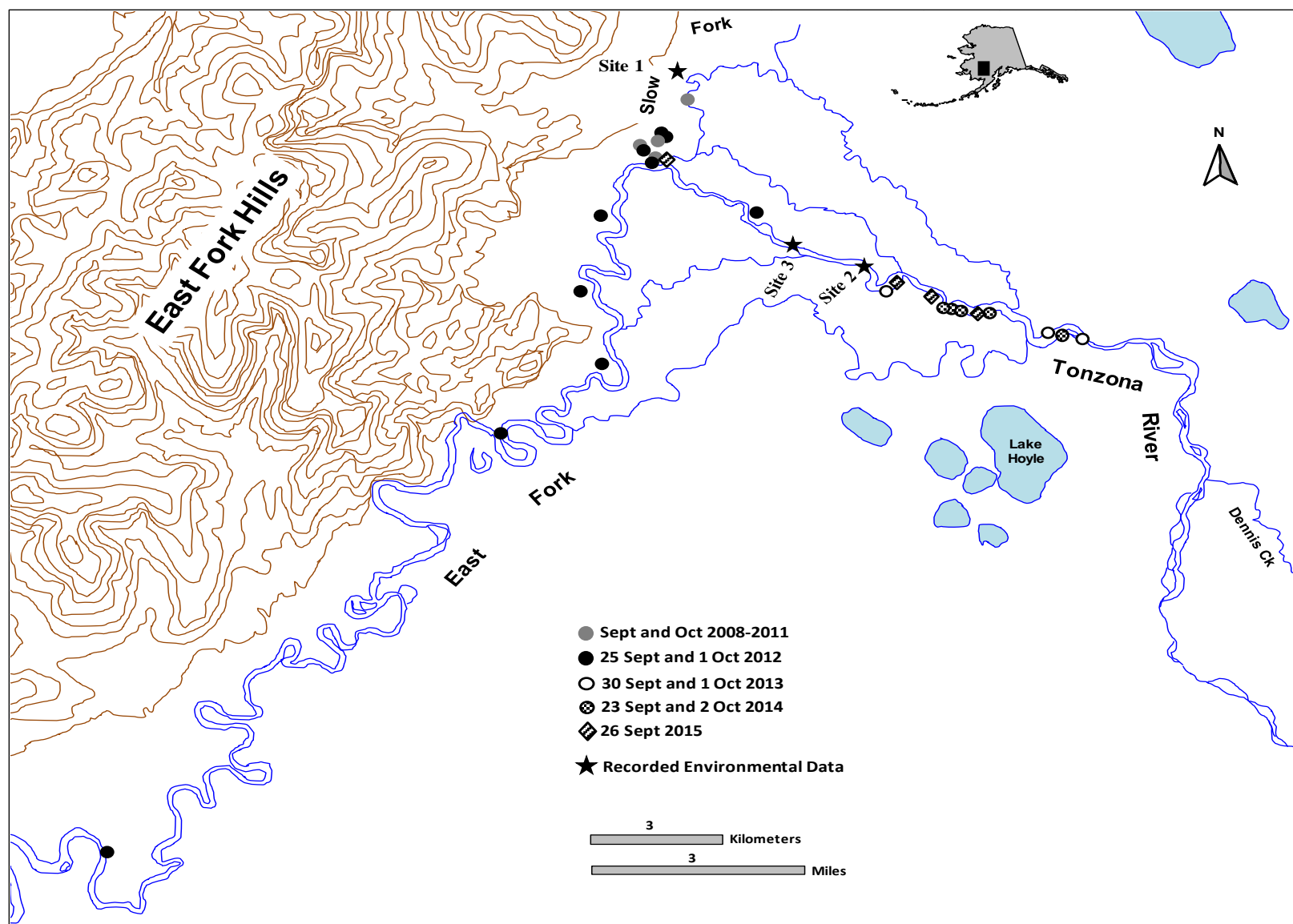


Figure 4.—Map showing locations of radiotagged sheefish on the East Fork Kuskokwim River and Tonzona River during the 2008–2015 September and October aerial tracking flights.

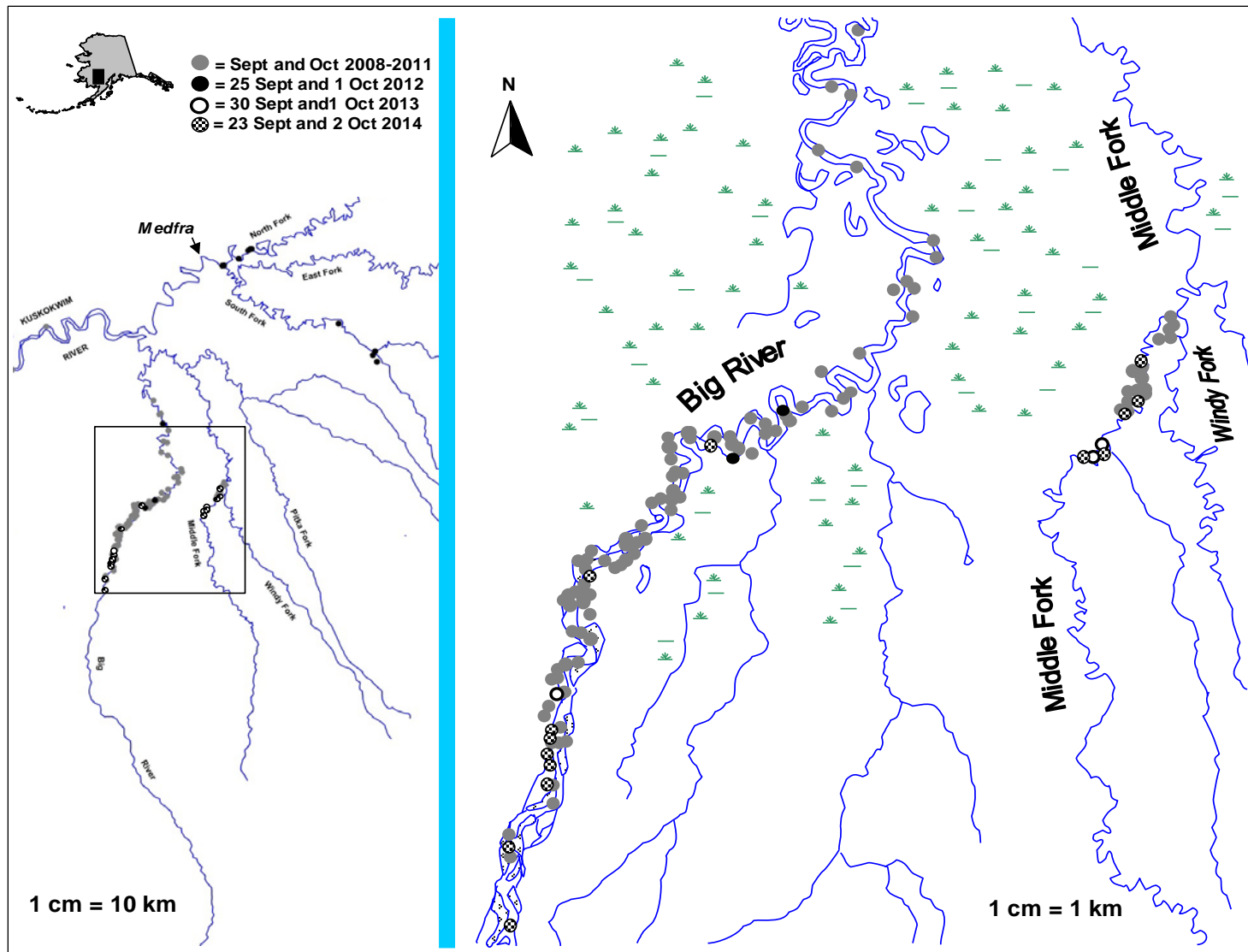


Figure 5.—Map showing locations of sheefish that were captured and radiotagged during 2008–2011 (Stuby 2012) and 2012–2014 on the Big River and Middle Fork during September and October aerial tracking flights. Inclement weather precluded flying over these drainages in 2015.

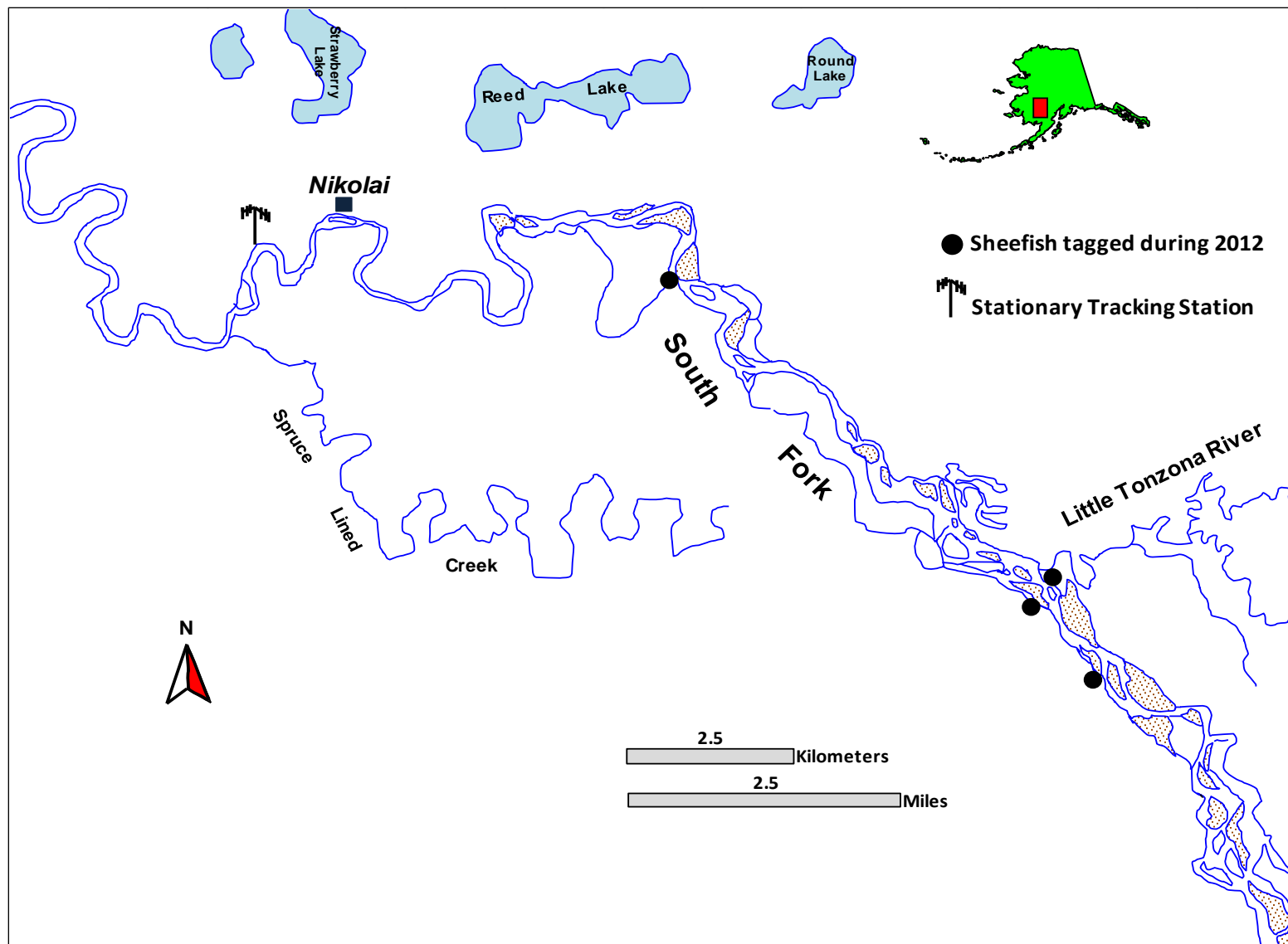


Figure 6.—Map showing locations of radiotagged sheefish on the South Fork Kuskokwim River near the confluence with the Little Tonzona River during the 2012 September and October aerial tracking flights.

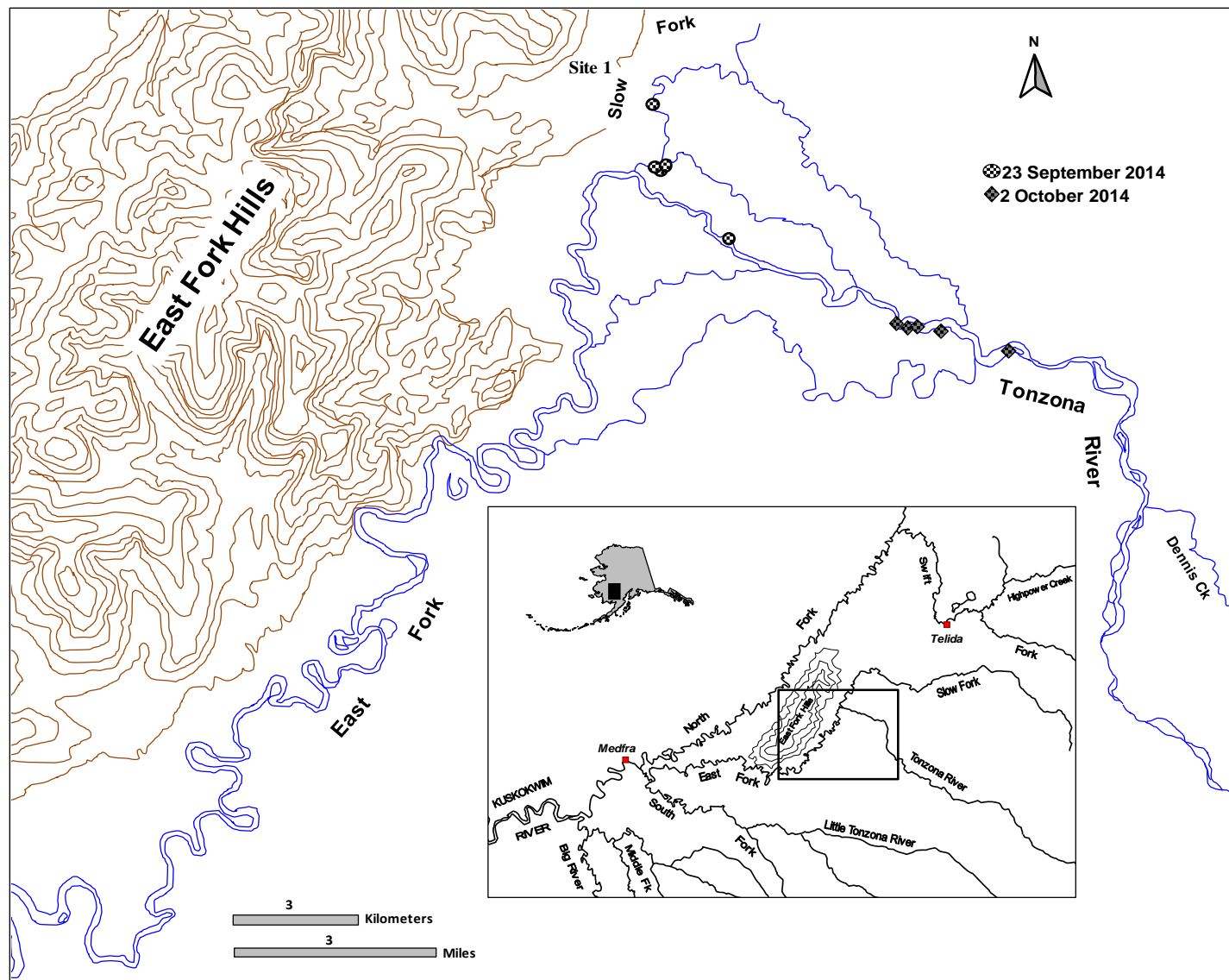


Figure 7.—Map showing pre-spawning milling and upriver movement 9 days later as radiotagged sheefish move into spawning locations on the Tonzona River.

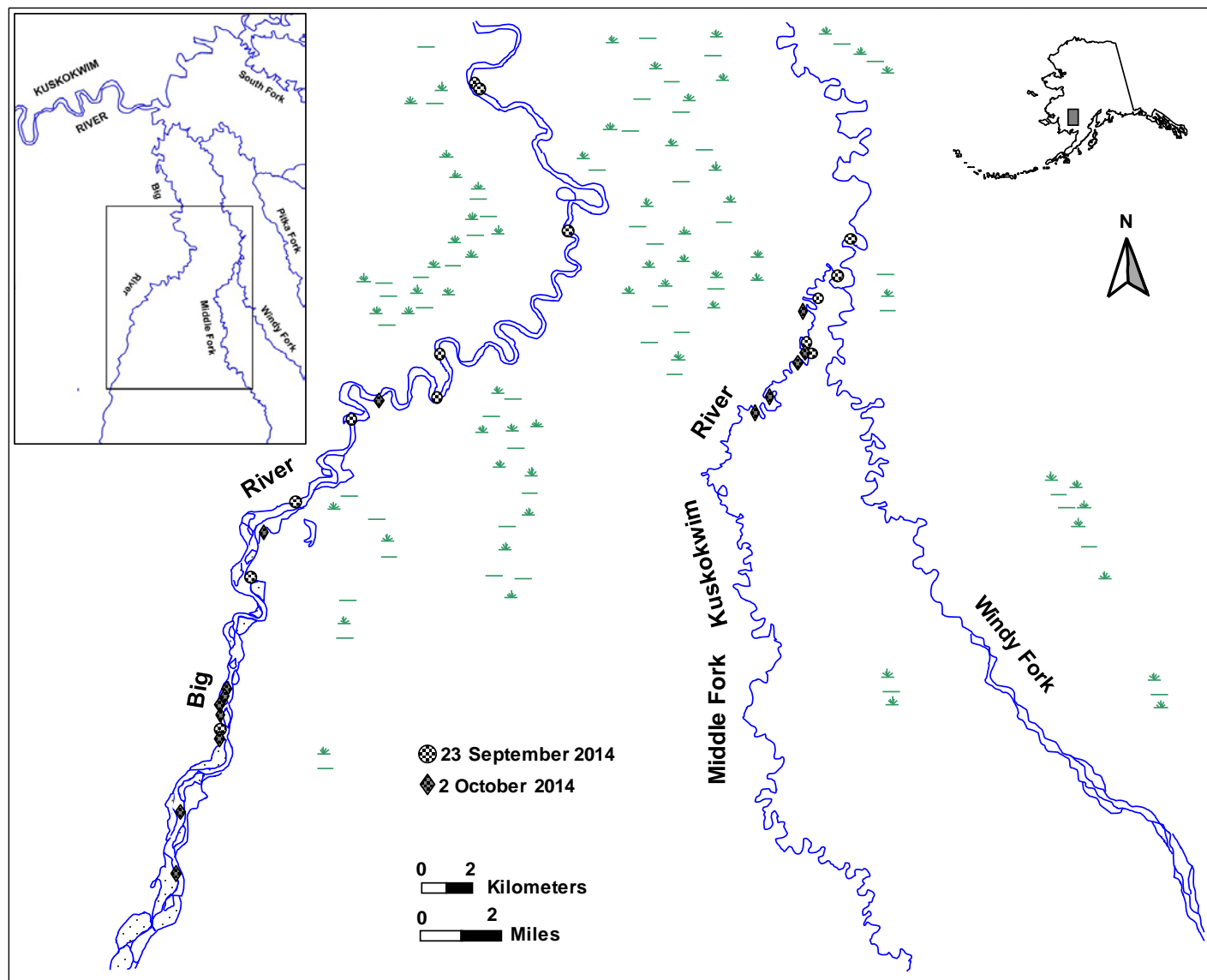


Figure 8.—Map showing pre-spawning milling and upriver movement 9 days later as radiotagged sheefish move into spawning locations on the Big River and Middle Fork

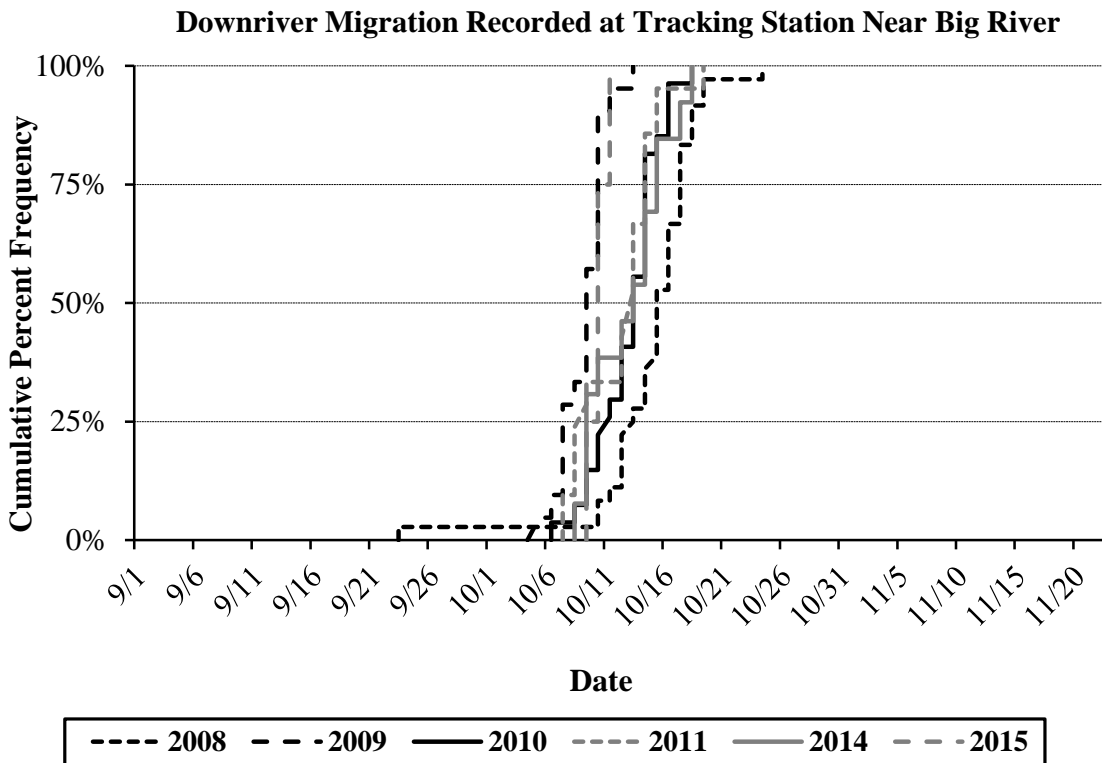
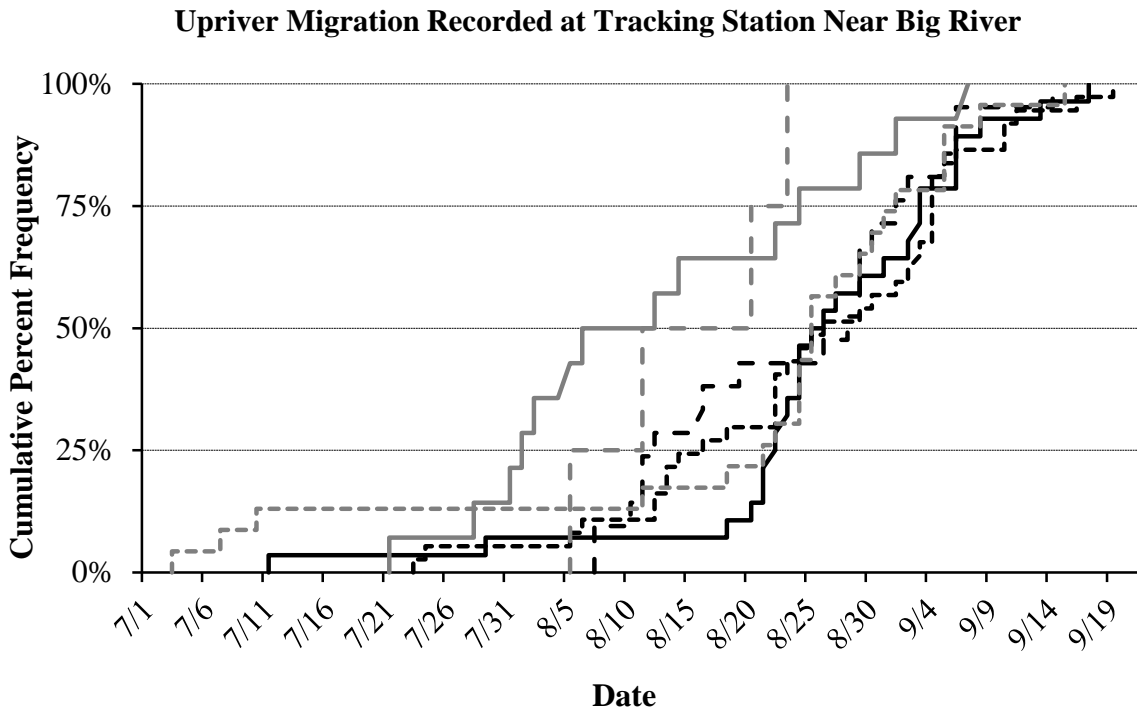


Figure 9.—Cumulative arrival and departure dates for radiotagged sheefish that migrated to upriver spawning areas on the Big River and Middle Fork Kuskokwim River during 2008–2011 (Stuby 2012) and 2014–2015.

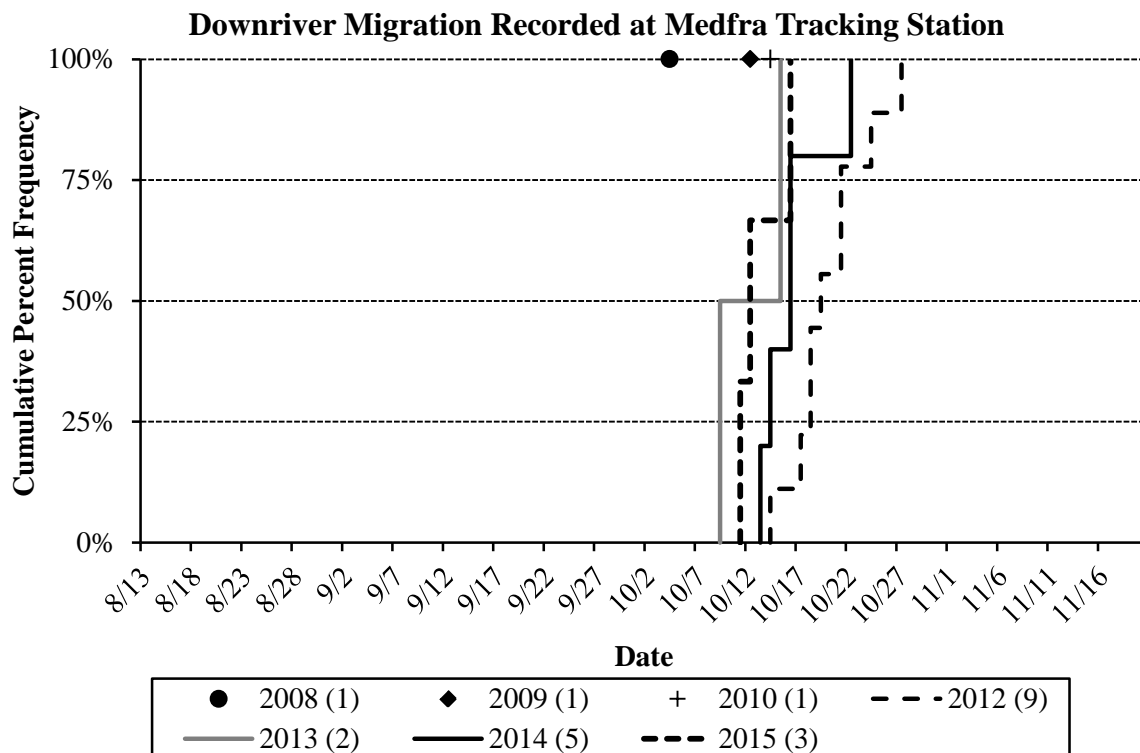
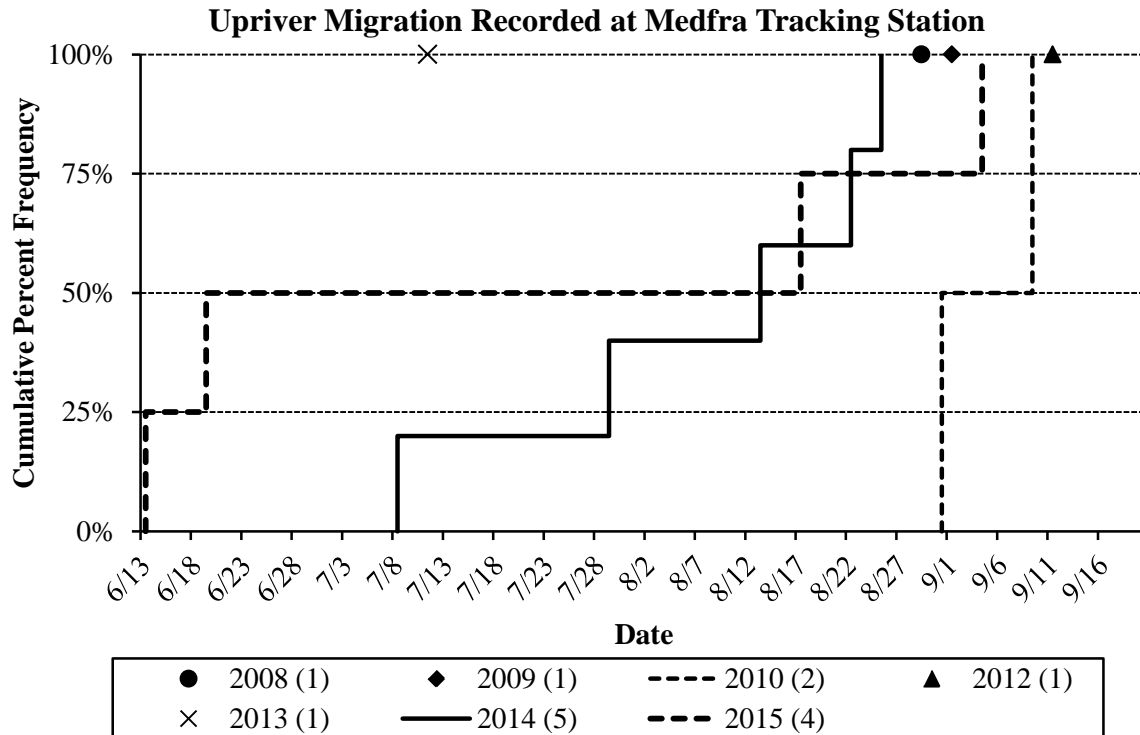


Figure 10.—Upriver and downriver migration dates for Tonzona River spawning sheefish past the Medfra tracking station. This station is located approximately 137 km downriver from the Tonzona River. Numbers of fish noted to travel are in parenthesis next to the year. Two samples or more are represented by a series line. Years 2008–2011 are from Stuby (2012).

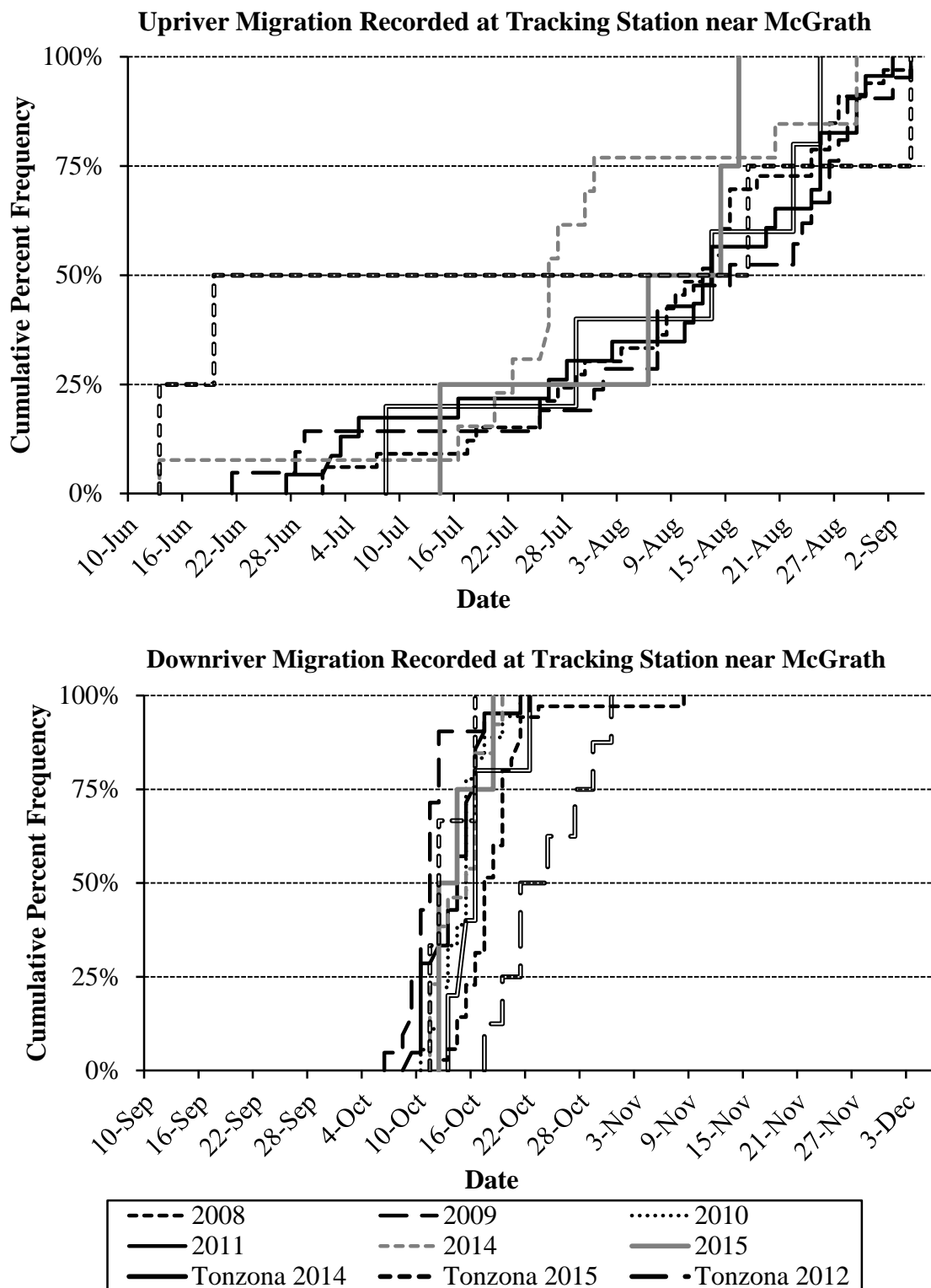


Figure 11.—Cumulative percent frequency distributions of in- and outmigrating radiotagged sheefish to the Big River and Middle Fork Kuskokwim River spawning areas during 2008–2011 (Stuby 2012) and 2014–2015 compared to those travelling to and from the Tonzona River spawning area in 2014 and 2015 past the McGrath tracking station.

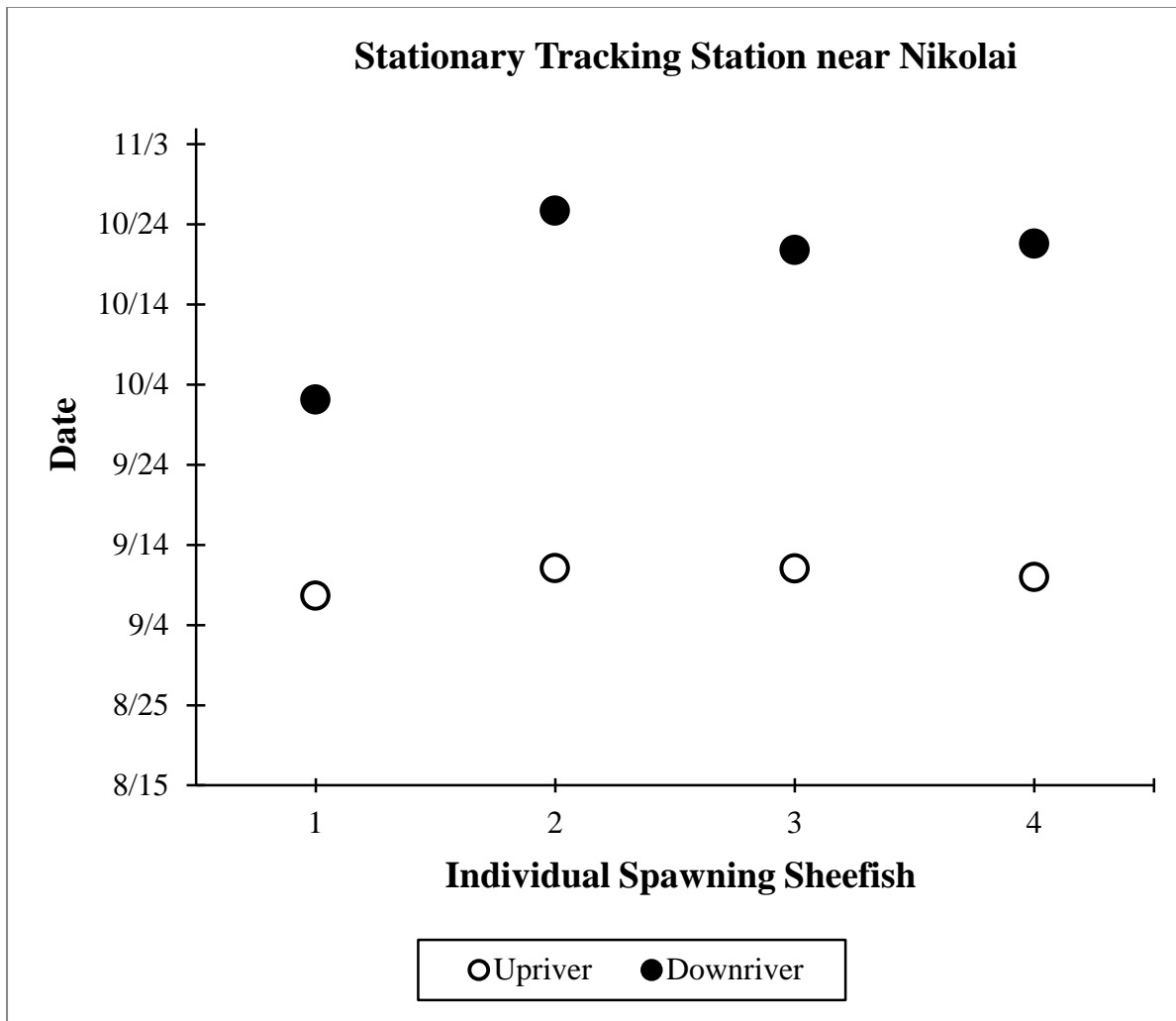


Figure 12.—Dates of passage for the 4 sheefish that travelled past the stationary tracking station near Nikolai to an undocumented spawning area near the Little Tonzona River.

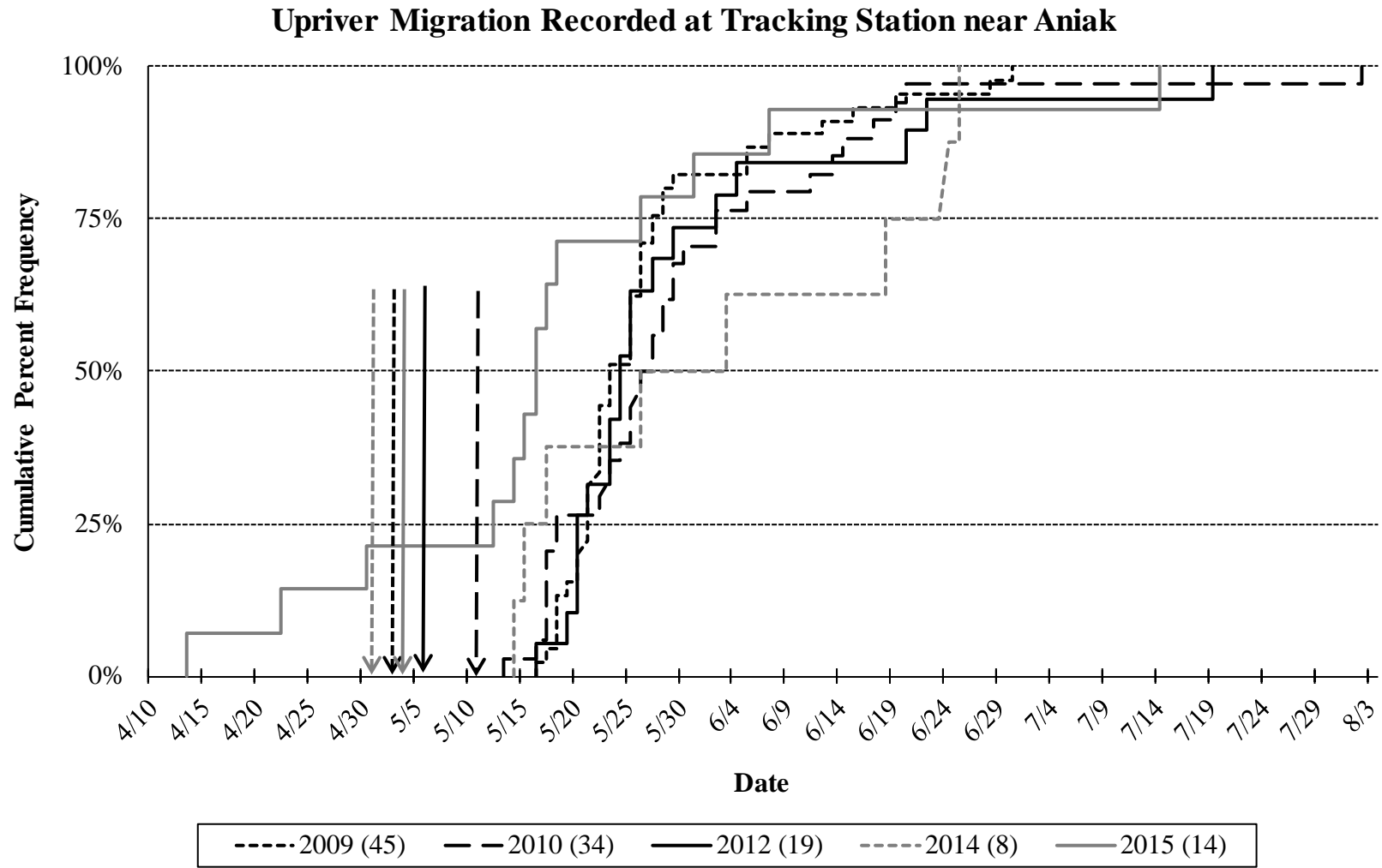


Figure 13.—Upriver migration times of radiotagged sheefish during 2009, 2010, 2012, 2014, and 2015. Arrows represent dates of spring ice out on the Kuskokwim River at Aniak. Years 2009–2010 are from Stuby (2012).

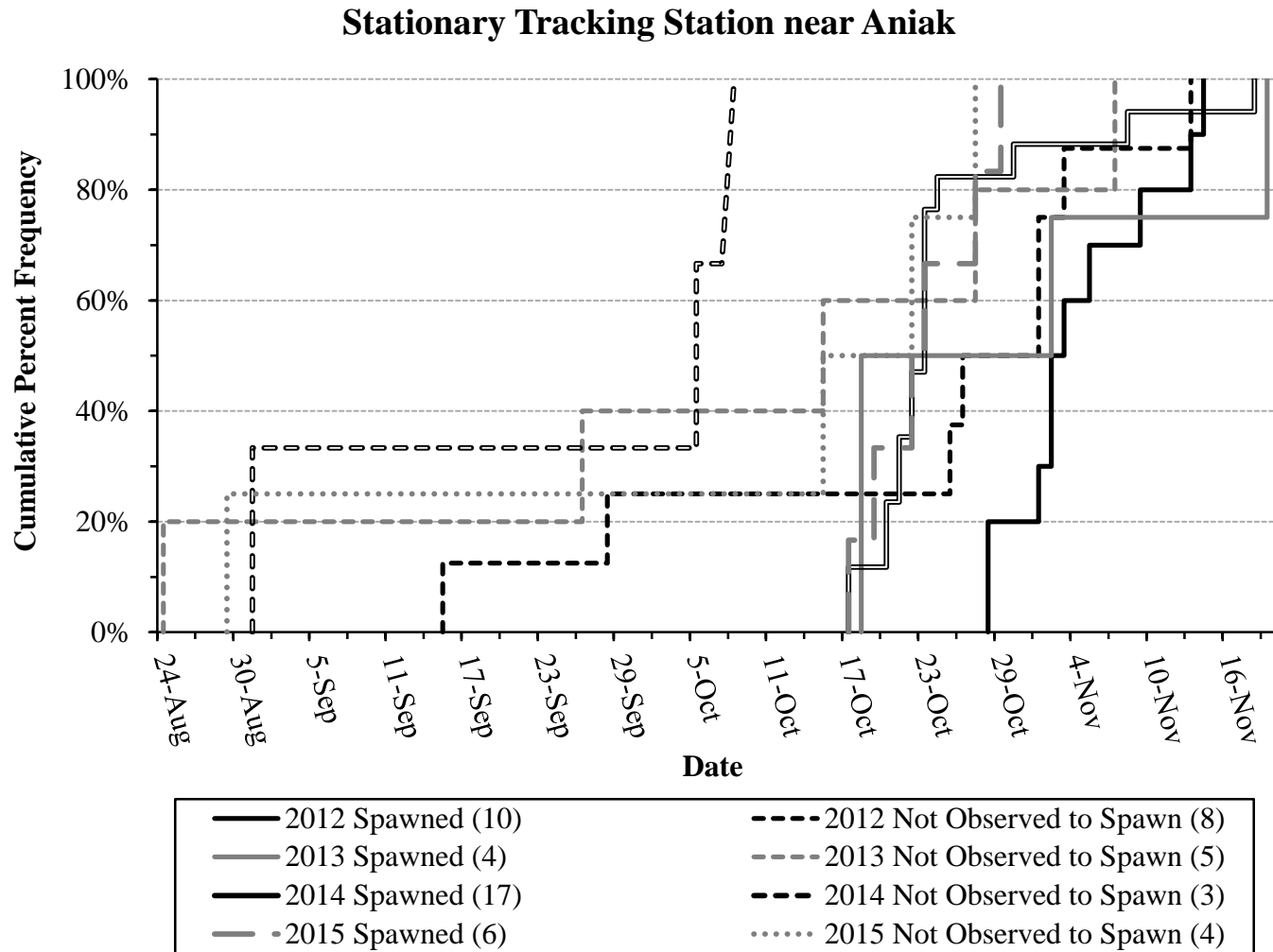


Figure 14.—Cumulative downriver passage dates past the stationary tracking station located near Aniak for spawning and non-spawning sheefish during 2012–2015.

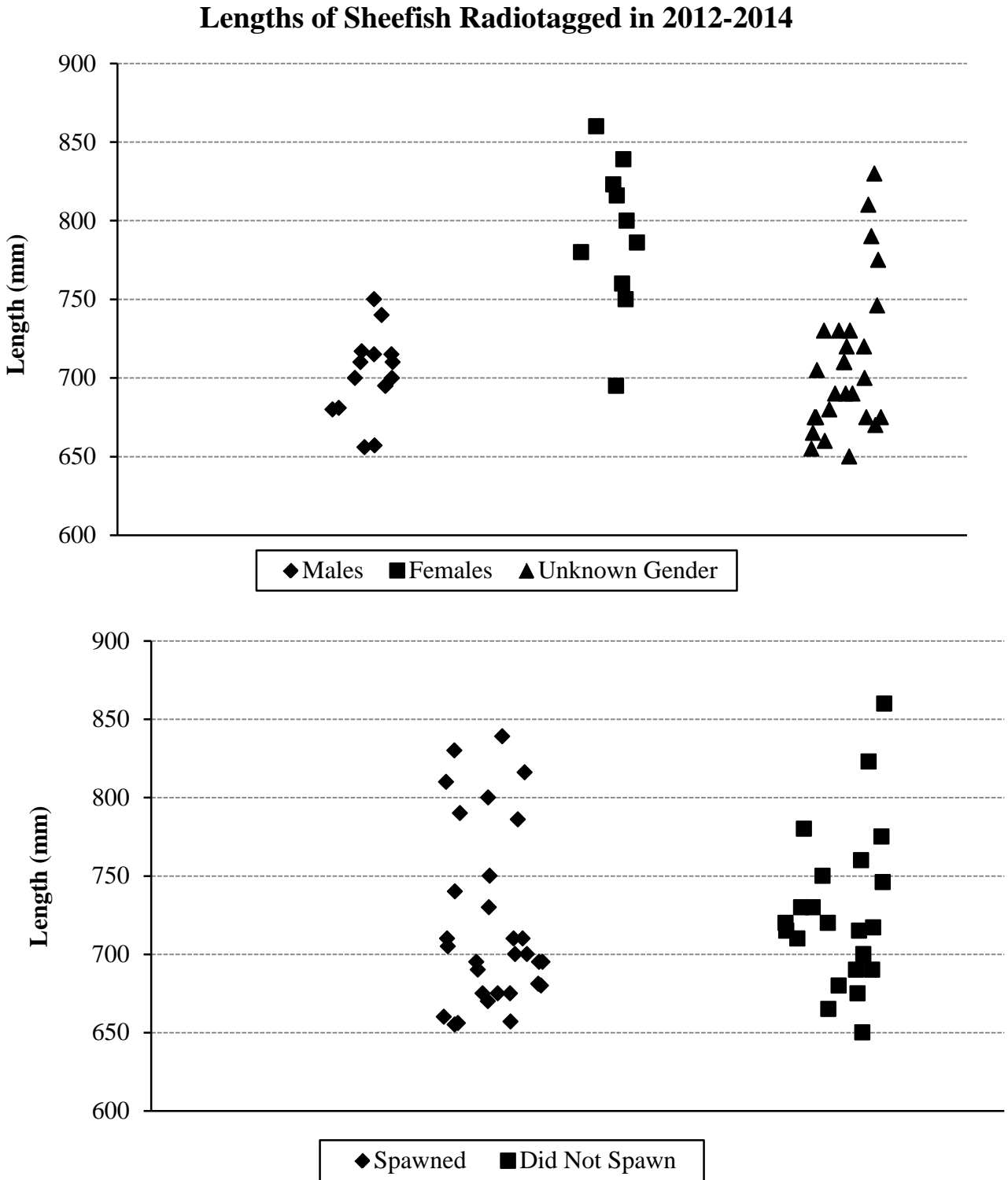


Figure 15.—Length and gender of the 52 sheefish that were captured and radiotagged during 2012–2014 on the North Fork near the confluence with the East Fork and at the mouths of the Takotna and Katlitna rivers and Blackwater Creek. Each symbol represents an individual fish.

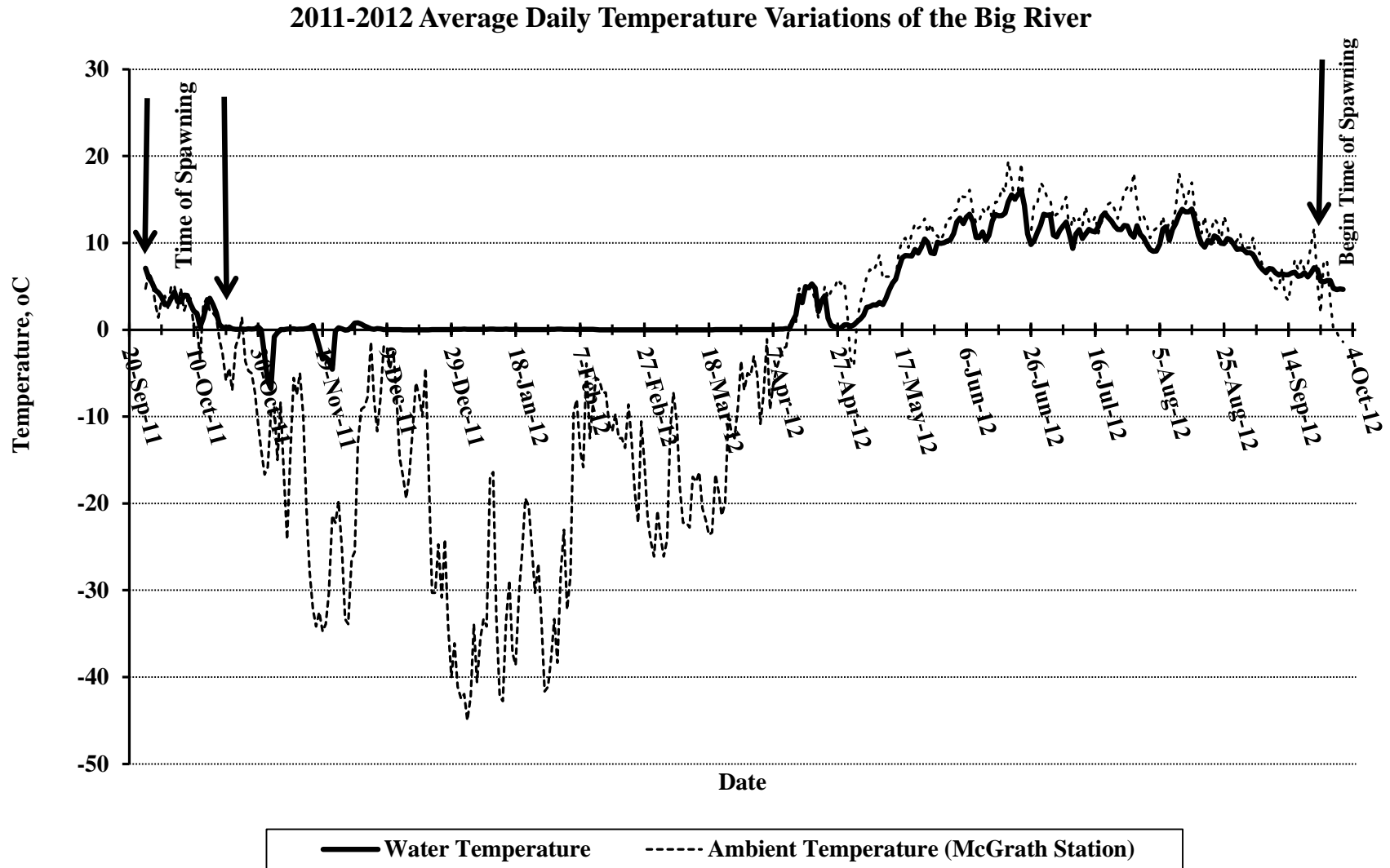
APPENDIX A:
ENVIRONMENTAL DATA COLLECTED DURING 2011–2013 FROM
HIGHPOWER CREEK; SWIFT, MIDDLE, AND SLOW FORKS; AND
THE TONZONA AND BIG RIVERS

Appendix A1.—Environmental characteristics recorded near the mouth of Slow Fork and on the Tonzona River during 2013, at the mouth of Highpower Creek and the Swift Fork during 2012, and the Middle Fork and Big River during 2011. Site locations illustrated in Figures 2 and 4.

Date/Time	Site ^a	DO		pH	Temperature	Conductivity	Secchi depth	Flow rate
		mg/L	%		°C	us/cm	m	m/sec
Highpower Creek								
9/15/12 10:45	1	11.38	89.3%	8.11	3.9	291	1.22	0.36
9/15/12 10:45	2	11.42	89.4%	8.17	3.8	293	1.83	0.45
9/15/12 13:00	3	11.24	89.3%	8.11	4.3	290	-	-
Swift Fork								
9/15/12 15:30	4	12.03	96.8%	8.20	4.8	379	-	-
9/15/12 16:00	5	12.09	96.9%	8.24	4.9	380	0.61	0.62
9/15/12 16:30	6	12.03	96.8%	-	4.8	-	0.91	0.63
9/25/13 14:00	6	12.99	97.1%	8.22	2.0	351	-	-
Slow Fork								
9/19/13 15:15	1	10.63	82.6%	7.58	3.7	222	1.22	-
Tonzona River								
9/19/13 17:00	2	12.52	97.2%	8.28	3.7	514	0.28	-
9/19/13 17:35	3	12.56	97.5%	8.34	3.7	513	0.28	-
Middle Fork ^a								
9/21/11 12:20	1	11.22	92.5%	8.27	4.9	356	1.78	0.54
9/21/11 15:25	2	11.21	94.4%	8.26	5.7	357	0.61	0.71
9/22/11 11:22	3	11.51	92.6%	8.13	4.7	358	0.61	0.15
9/22/11 11:22	3	-	-	8.21	-	-	1.37	-
Big River ^a								
9/25/11 15:53	1	11.64	99.1%	8.29	7.1	380	0.84	1.01
9/25/11 17:00	2	11.63	99.2%	8.37	7.1	380	0.61	0.83
9/25/11 17:40	3	11.60	98.8%	8.34	7.1	379	0.76	0.36

^a For maps of site locations for the Middle Fork of the Kuskokwim River and Big River see Appendices C1-C3 of Stuby (2012).

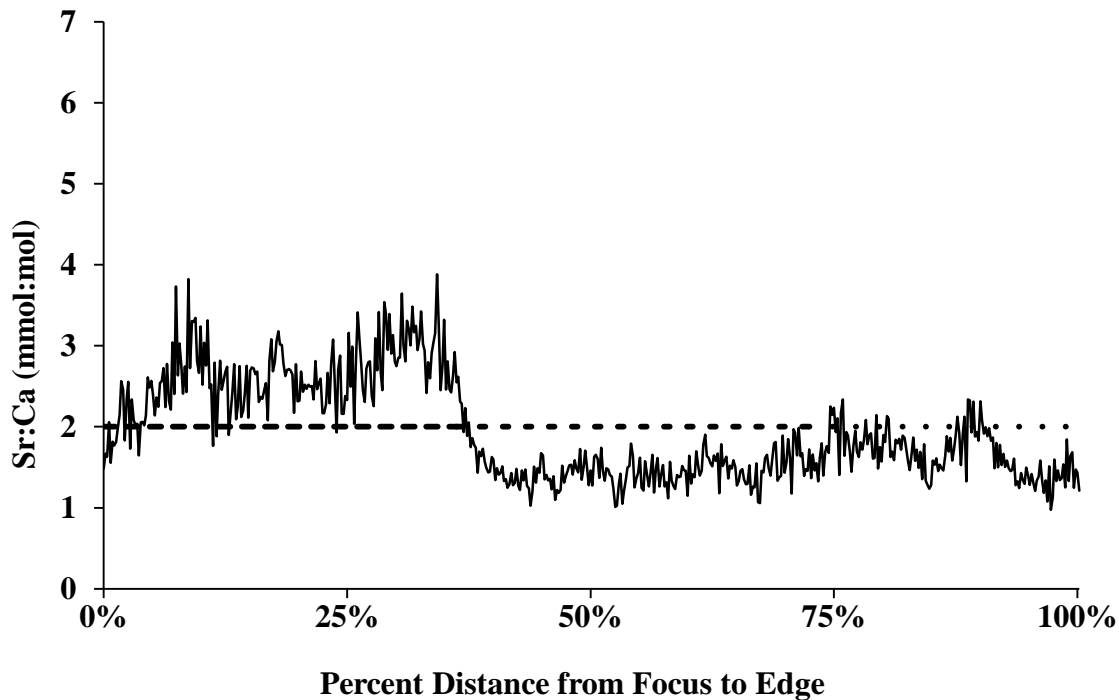
Appendix A2.—Daily average temperatures of Big River recorded by an Onset HOBO water temperature sensor and corresponding average ambient temperatures from McGrath Station during 25 September 2011 to 1 October 2012.



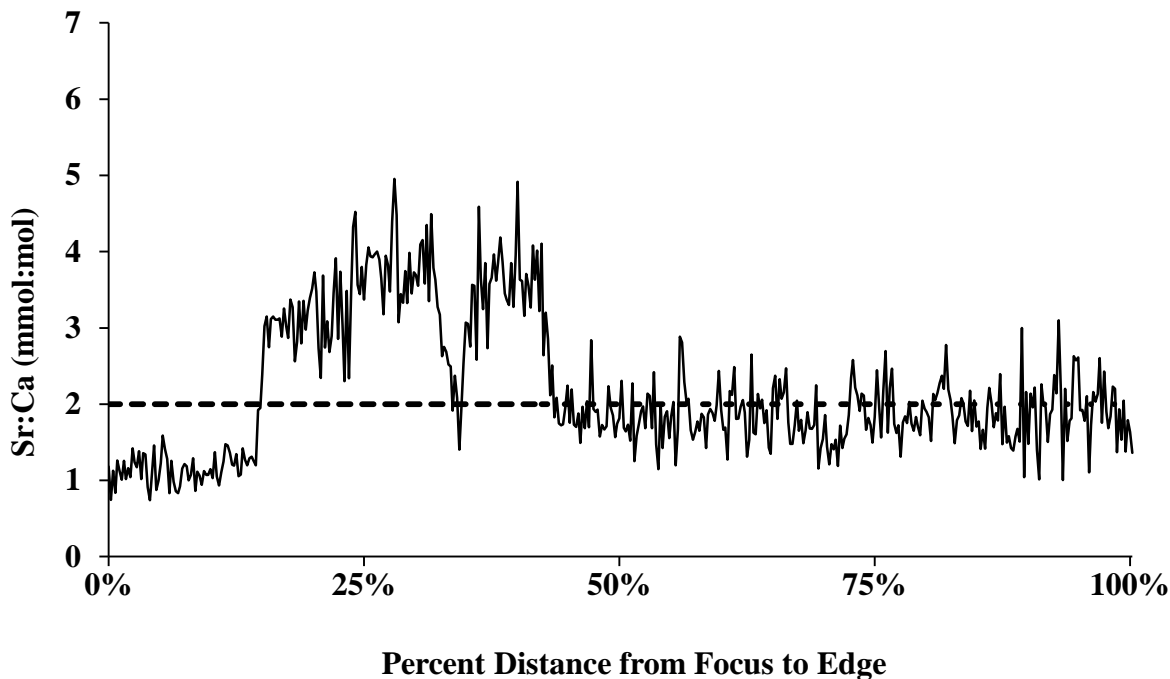
APPENDIX B:
MICROCHEMISTRY RESULTS FOR OTOLITHS SAMPLED FROM
THE BIG RIVER, MIDDLE FORK KUSKOKWIM RIVER, AND
TONZONA RIVER SPAWNING SHEEFISH

Appendix B1.—Sr:Ca profiles of otoliths collected during September 2011 showing clear anadromy. Values above the 2.0 Sr:Ca (mmol:mol) threshold reflect marine influence and below 2.0 reflect freshwater. Values near the threshold reflect brackish water influence.

Middle Fork Female, 865 mm, 13 Years

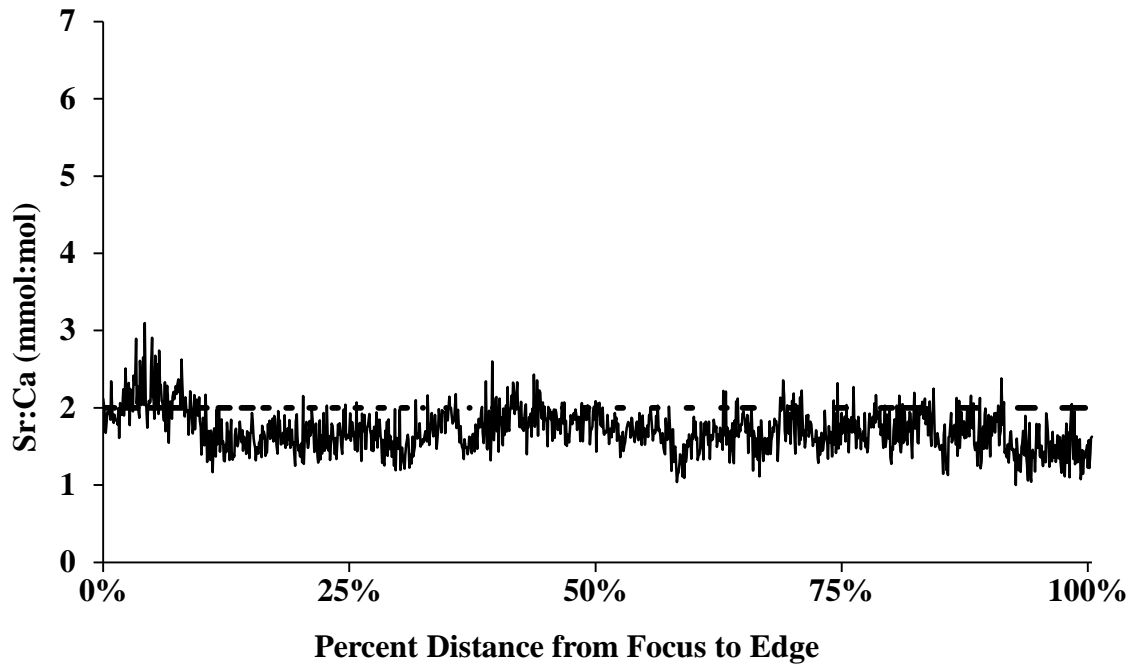


Big River Male, 735 mm, 21 Years

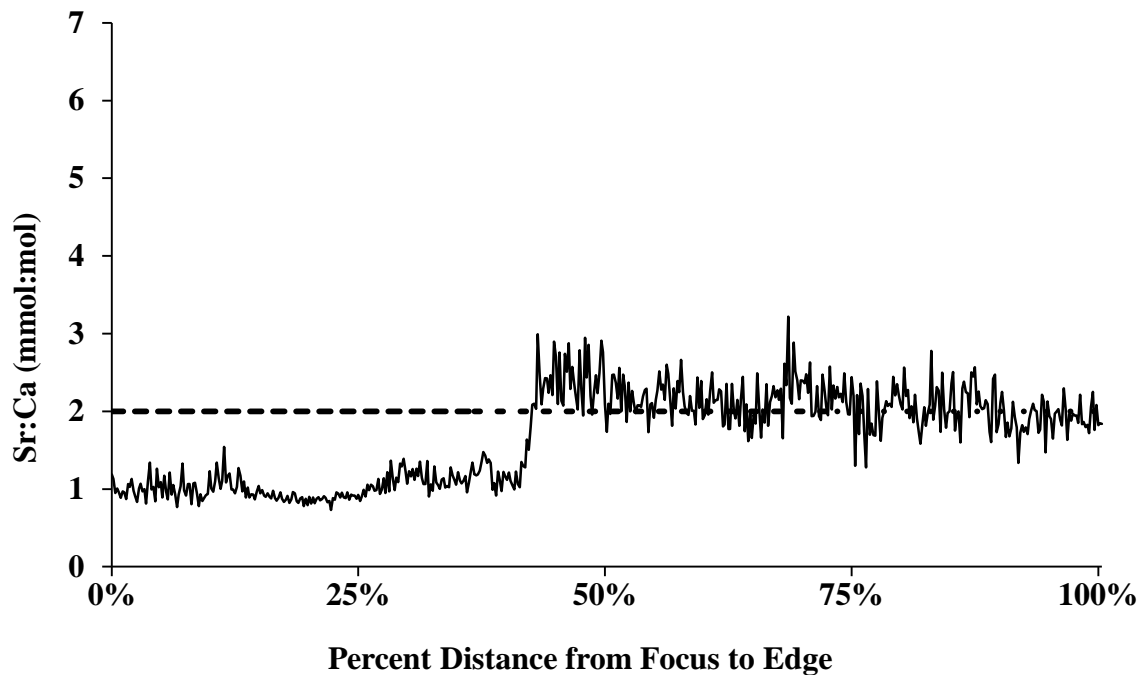


Appendix B2.—Sr:Ca profiles of otoliths collected during September 2011 showing likely anadromy and/or that the sheefish entered brackish water in the Lower Kuskokwim River. Values above the 2.0 Sr:Ca (mmol:mol) threshold reflect marine influence and below 2.0 reflect freshwater. Values near the threshold reflect brackish water influence. Big River female age from fin ray.

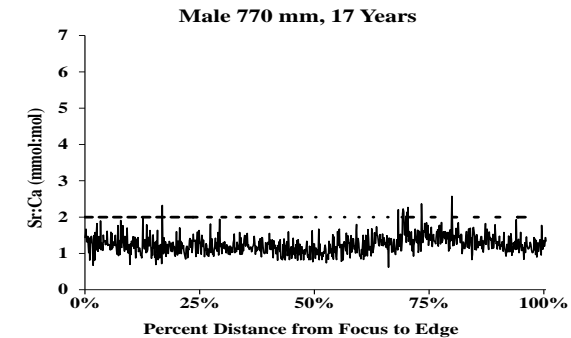
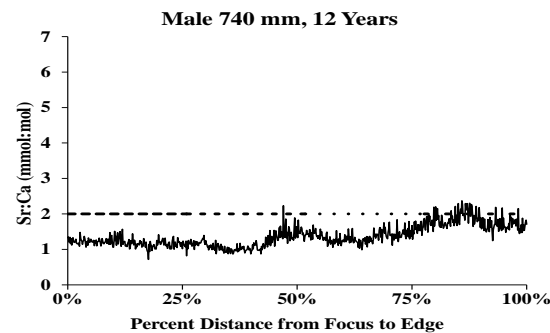
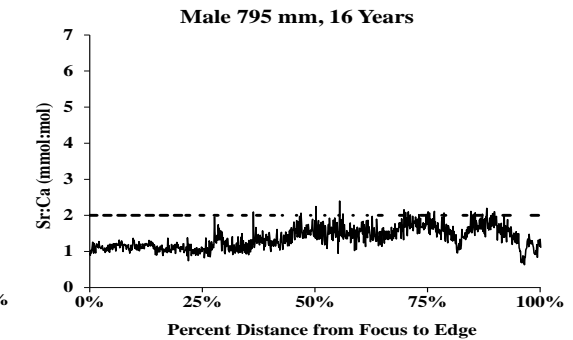
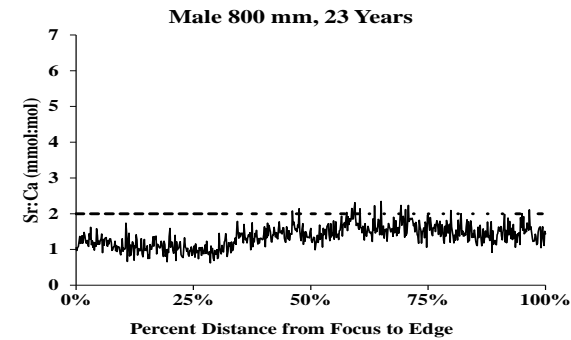
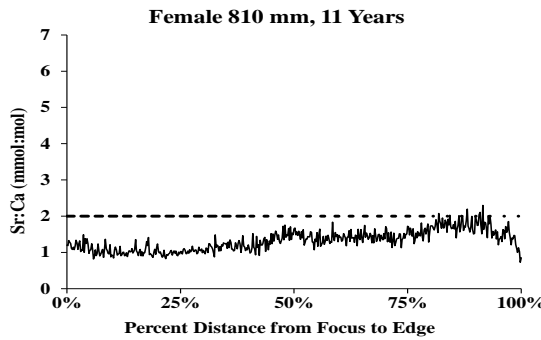
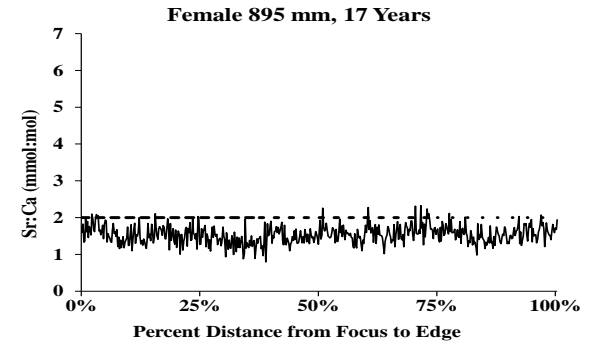
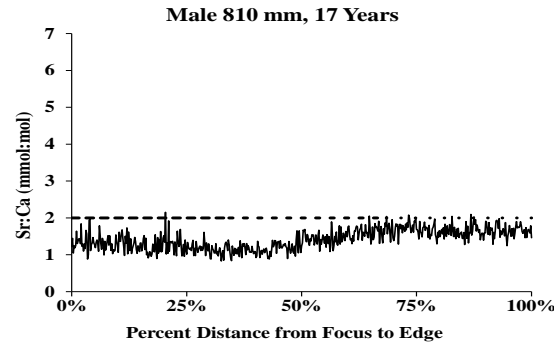
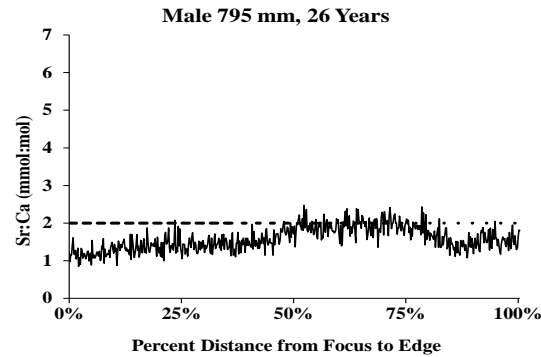
Big River Female, 755 mm, 9 Years



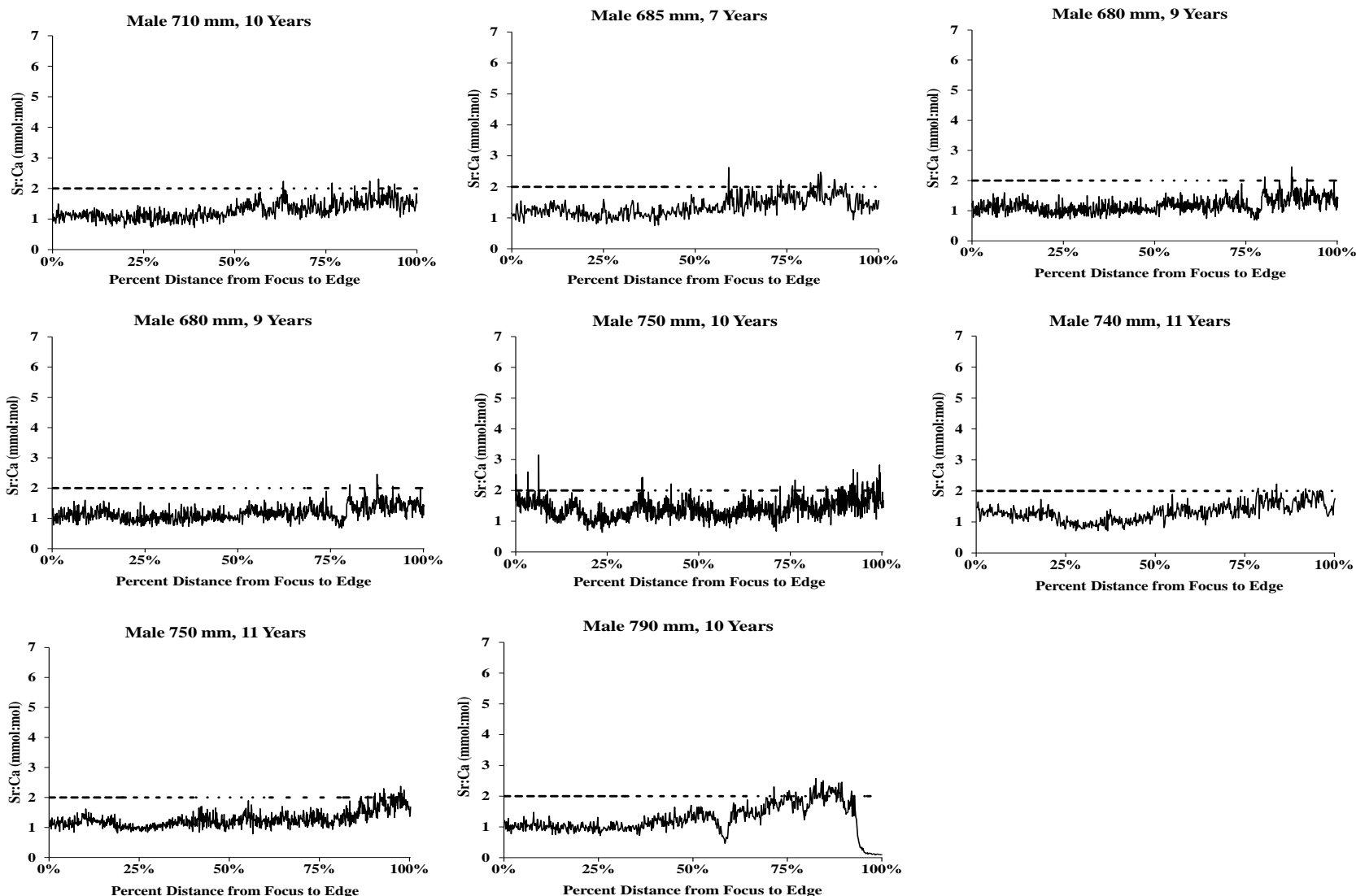
Middle Fork Male, 780 mm, 12 Years



Appendix B3.—Sr:Ca profiles of otoliths showing sheefish collected in September 2011 from the Big River to be non-anadromous and that they may have encountered lightly brackish water in the Lower Kuskokwim River. Values above the 2.0 Sr:Ca (mmol:mol) threshold reflect marine influence and below 2.0 reflect freshwater. Values near the threshold reflect brackish water influence.

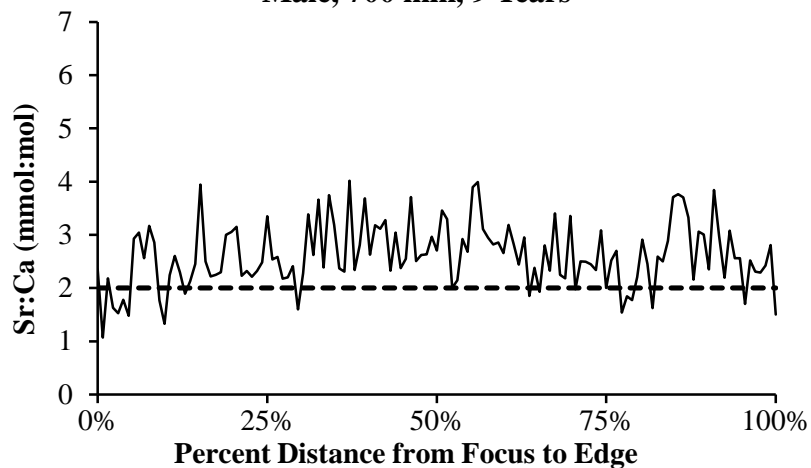


Appendix B4.—Sr:Ca profiles of otoliths showing sheefish collected during 2011 from the Middle Fork to be non-anadromous or they may have encountered lightly brackish water in the Lower Kuskokwim River. Values above the 2.0 Sr:Ca (mmol:mol) threshold reflect marine influence and below 2.0 reflect freshwater. Values near the threshold reflect brackish water influence

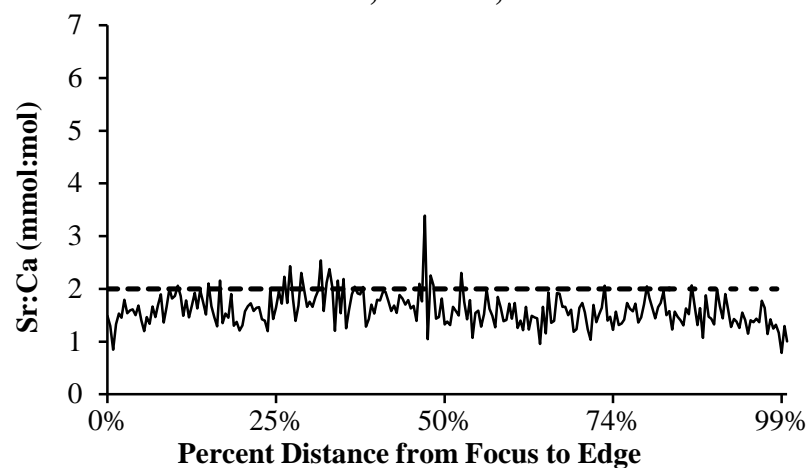


Appendix B5.—Sr:Ca profiles of sheefish otoliths collected during 2013 from the Slow Fork confluence with the Tonzona River. Upper left shows clear anadromy and upper right shows likely anadromy and/or the sheefish entered brackish water in the Lower Kuskokwim River. The bottom 2 illustrates non-anadromy or the 2 fish encountered lightly brackish water in the Lower Kuskokwim River. Values above the 2.0 Sr:Ca (mmol:mol) threshold reflect marine influence and below 2.0 reflect freshwater. Values near the threshold reflect brackish water influence. Ages taken from pectoral fin rays.

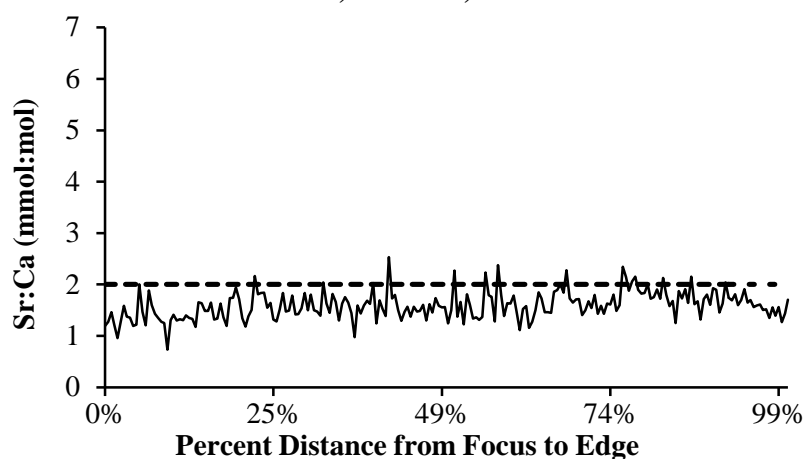
Male, 700 mm, 9 Years



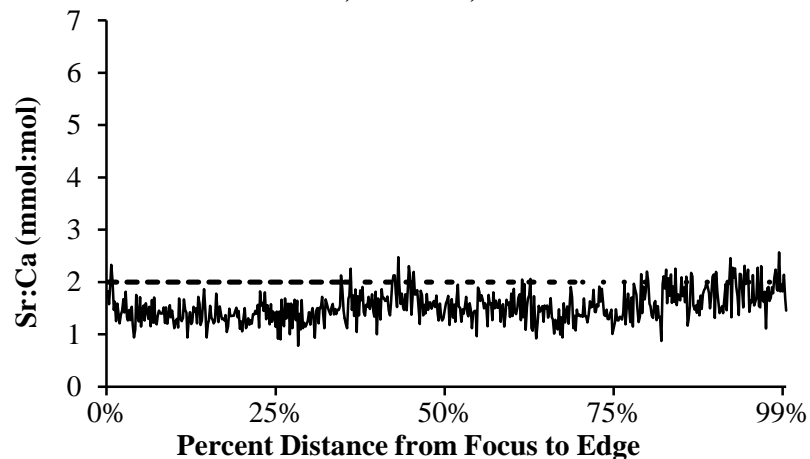
Female, 790 mm, 10 Years



Male, 725 mm, 9 Years



Male, 705 mm, 8 Years



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